The craft of incentive prize design

Lessons from the public sector

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Executive summary

IN the last five years, incentive prizes have transformed from an exotic open innovation tool to a proven innovation strategy for the public, private, and philanthropic sectors. Incentive prizes seem deceptively simple: Identify a problem, create and publicize a prize-based challenge for solving that problem, sign up diverse participants, and offer a reward to the winner. In practice, designing prizes that target the right problem, attract the most capable participants, and capture the imagination of the public to successfully achieve a desired outcome involves a complex set of design choices. This report aims to help prize designers organize and master those choices.

In the past, designers thought of prize types as distinct tools, often seeking to match the right tool to the problem they were seeking to address. Now, prize design has become a craft. Experienced designers help their organizations achieve a range of outcomes by building highly customized prizes and deploying them in concert with other problem solving and public engagement strategies. They focus less on what type of prize to use and more on how to assemble the fundamental elements of prize design through a series of integrated design choices informed by research and analysis. While this approach is understandably more complex than simply pulling a prize out of a toolbox, it also enables more sophisticated prize designs, allowing organizations to more effectively get what they need.

The craft of incentive prize design offers practical lessons for public sector leaders and their counterparts in the philanthropic and private sectors. It helps them to understand:

1. What types of outcomes incentive prizes help to achieve

2. What design elements prize designers use to create these challenges

3. How to make smart design choices when launching an incentive prize to achieve a particular outcome

This report treats prize design not as a linear, step-by-step process, but rather as an iterative activity that requires making integrated choices to solve a carefully defined problem and then generating outputs that achieve a larger set of outcomes. By synthesizing insights from recent literature, expert interviews, and analysis of over 400 prizes, we identify six outcomes that designers commonly seek (individually or in combination), falling along two dimensions:

Developing ideas, technologies, products, or services

- Attract new ideas
- Build prototypes and launch pilots
- Stimulate markets

Engaging people, organizations, and communities

- Raise awareness
- Mobilize action
- Inspire transformation

The first dimension captures the range of conceptual and tangible things which designers

are trying to develop. The second reflects how prizes can incent individuals, groups, organizations, and institutions to get involved in solving important public sector problems. In most cases, incentive prizes aim for outcomes on both dimensions. Looking at prizes through the lens of outcomes allows designers to establish a stronger link between what their organizations are trying to do and the benefits that prizes can help generate.

We use the phrase "elements of prize design" to describe and organize the strategic choices that designers should consider when crafting incentive prizes. There are five core design elements: resources, evaluation, motivators, structure, and communications. The heart of this report features practical decision-oriented frameworks for designers, helping them understand how they can tailor prize design elements to facilitate different outcomes and increase the effectiveness of their challenges.

Through decision-oriented frameworks that link outcomes to design elements, *The craft of incentive prize design* enables public, philanthropic, and private sector leaders to build better prizes. The report helps these leaders benefit from the recent experiences of designers who are advancing the art of incentive prize design in the service of the public good. By accessing these experiences, illustrated with recent examples of successful prizes, designers can more effectively harness the ingenuity of the public to address their most vexing challenges.

Introduction

ON January 12, 2010, a 7.0-magnitude earthquake devastated Haiti, affecting three million people and destroying significant portions of the nation's fragile infrastructure. Many organizations flooded Haiti with support, offering different forms of assistance to rebuild the country.[1] Among them were USAID and the Gates Foundation, which recognized the critical need for jump-starting financial services, the backbone of any functioning modern economy. Working together, they designed a prize that incented new mobile money service providers to launch in Haiti and achieve specific operational and transactional milestones.

Called the Haiti Mobile Money Initiative, this incentive prize helped stimulate a new mobile money market in Haiti, where, before the earthquake, only 10 percent of the population used traditional banks. It featured $10 million in awards, broken into different-sized purses, some to incent first-to-market services and others to encourage scaling customer adoption. To increase the initiative's effectiveness using more traditional sources of aid, USAID contributed $5 million in technical and management assistance. Within six months of launch, two mobile banking service providers were up and running. By October 2011, both participants won scaling awards for more than 100,000 transactions;[2] less than a year later, one participant achieved the 5 million transaction milestone.

The Haiti Mobile Money Initiative powerfully illustrates how the craft of prize design has rapidly evolved in recent years, thanks to public, private, and philanthropic organizations that are using prizes to innovate in the service of the public good. Leaders and prize designers in these organizations are learning through experience that incentive prizes can meaningfully advance their missions. In the process, they are also discovering that successful prize design involves a complex series of choices to attract the right competitors with the knowledge and experience needed to solve a wide range of complex problems.

While prizes confer many benefits, their primary appeal is allowing leaders to pay *only* for satisfactory results. Competitors receive compensation, in whatever form it may take, only if they meet the evaluation criteria established by the prize's designer. That is not to say that incentive prizes can or should be used only when results can be guaranteed. Some designers are following a higher-risk, higher-reward strategy of using prizes to achieve goals that cannot be specified in advance. As budgets tighten in every sphere while the demand for innovation is rising, prizes are becoming recognized as a promising method to address an array of problems, often more efficiently and effectively than traditional approaches.

From the development of new technology prototypes to the reduction of energy consumption to challenges that help prevent child slavery, prize designers are capturing the public's imagination and unlocking their creativity.

Government and philanthropic leaders view prizes as a vehicle to drive change and describe the experience of implementing a prize to be a valuable problem-solving exercise in and of itself.

While prizes are not new, the idea that prize design is a craft that organizations should master to launch successful challenges has gained significant currency. The White House's Office of Science and Technology Policy dedicates personnel to help federal departments and agencies design effective prizes. More than 50 federal departments and agencies have offered prizes and some federal agencies have added dedicated staff for prize design as well.[3] Many major US philanthropies are using prizes to advance their missions, as are dozens of state and local agencies throughout the United States. Organizations with an international focus, such as the World Bank, use prizes to drive innovation in the developing world. Specialized advisory service firms now provide prize technology platforms and strategic guidance to organizations that lack the skills and capabilities needed to design and implement their own challenges.

All of this activity has yielded lessons and strategies that can help designers make choices about what kinds of prizes can generate specific outputs in the service of larger outcomes. They are learning to use prizes to achieve different but mutually reinforcing outcomes and finding ways to match prizes with other complementary problem-solving strategies. By experimenting with the elements of prize design and building on what they learn, designers have begun creating more sophisticated prize structures that can engage a broader group of qualified participants through multiple stages of competition. From the development of new technology prototypes to the reduction of energy consumption to challenges that help prevent child slavery, prize designers are capturing the public's imagination and unlocking their creativity.

Designers commonly seek six outcomes (individually or in combination) that fall along two dimensions:

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Engaging people, organizations, and communities

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The first dimension captures the range of conceptual and tangible things which designers are trying to develop through incentive prizes. The second reflects how prizes can incent individuals, groups, organizations, and institutions to get involved in solving important problems. These dimensions represent intermediary and complementary outcomes that can be achieved during and after the execution of a prize. Looking at prize design through the lens of outcomes allows designers to establish a stronger link between what their organizations aspire to do and the specific outputs that prizes can generate.

By using prizes to achieve these outcomes, designers are generating whole innovation ecosystems. Prizes build and maintain communities of interest that help organizations address complex, ambiguous problems. Prizes educate the public and encourage citizen participation in new and dynamic ways. Prizes create opportunities for public organizations to share costs with private and philanthropic partners. They foster collaboration among government, academia, the private sector, and individuals.[4] Some organizations even use prizes to shape commercial markets, either to develop technologies, goods, and services directly or to bring innovative prototypes to market for the first time. Most importantly, prizes also demonstrate that government can innovate in service of the public good and open up problem solving to leverage the ingenuity of citizens and businesses.

As the use of prizes grows, the language of prize design is becoming more specialized. One important and increasingly common distinction involves "outputs" and "outcomes." Prize designers use "outputs" to describe the specific end results of a prize, such as a software application (app) with particular functionality, the formation of a technical community around the development of that app, and even insights about how to improve that type of prize implementation. In contrast, prize designers use "outcomes," as we've described above, to reference more general and aspirational goals, which can be fulfilled by a prize as well as other approaches. For example, an agency may wish to pursue the outcome of building prototypes and launching pilots by designing and executing a prize that generates an app as an output. To achieve that outcome, the same agency may need to find ways to generate other, complementary outputs, such as a marketing campaign that introduces the app to target audiences. In sum, "output" and "outcome" help designers to distinguish tactical results from strategic objectives.

The growing appeal of prizes has also generated definitional confusion. "Prize" and "challenge" are often used interchangeably, making it difficult to distinguish between how these terms represent different ways to solve problems and, in the US government context, what legal authority permits an agency to solve a problem in a particular way. In this report, we will treat "challenges" as an umbrella term for a variety of problem solving approaches, including incentive prizes, grants, direct investments and partnerships, to name a few. While incentive prizes will be our focus, we will also draw lessons from different types of challenges, such as competitive grants, that can be applied to the craft of incentive prize design. We recognize that these distinctions are further complicated by the fact that US government agencies must conduct different types of challenges under specific legal authorities, such as the America COMPETES Act.[5] Federal leaders should consult their offices of general counsel to determine what legal authorities govern their ability to stimulate innovation, acquire particular goods or services, conduct research for the public good, or work with private organizations for mutual benefit.

> By drawing upon the rich challenge activity of the past five years, we aim to help designers understand what they can do with prizes, and how—practically speaking—they can assemble prize design elements in different ways to achieve these outcomes.

It has been five years since the advisory services firm McKinsey & Co. published the first major report on the use of prizes for philanthropy.[6] Since then, the US government alone has administered over 350 prizes. The prize typology featured in McKinsey's report had a significant influence on the first generation of public sector and philanthropic prize designers who needed an organizational structure to understand what kinds of prizes were possible to implement and when to use them. Because many designers still reference McKinsey's typology, this report seeks to build on it by focusing on the overarching outcomes that designers are trying to achieve and the fundamental elements of

prize design that experienced designers use. By drawing upon the rich challenge activity of the past five years, we aim to help designers understand what they can do with prizes, and how—practically speaking—they can assemble prize design elements in different ways to achieve these outcomes.

This report explores the craft of designing incentive prizes and shows how design choices can influence a prize's ability to solve vexing challenges by drawing links between outputs, outcomes, and the elements of prize design. While we focus on public sector incentive prizes in the United States, many of the trends and design lessons reported here are drawn from and are applicable to challenges launched by philanthropic and private organizations. In that spirit, we highlight examples from these sectors to illustrate how designers make strategic choices, and how those choices represent leading practices in this growing field. In the course of our research, we also evaluated challenge-related documents and interviewed prize experts from outside the United States. Our findings encompass these insights as well.

We intend the guidance featured in this report for all leaders interested in prize design, from neophytes to those who have already integrated prizes into their problem solving strategies. To appeal to this broad audience, the main body of this report will give an overview of prizes, their design, and the outcomes that they can achieve. Appendix A will provide additional guidance for more advanced designers.

Recognizing the diversity of experiences of prize designers, the report features decision-oriented frameworks that organize the now vast array of complex and distributed prize information. We deliberately created these frameworks to support iterative prize design, because many other excellent reports, such as Harvard Berkman Center's *Public-private partnerships for organizing and executing prize-based competitions* or Nesta's *Challenge prizes: A practice guide*, already take process-oriented approaches.[7]

While we have drawn useful information from recent academic literature, articles, and published commentary, much of our data is derived from in-depth interviews with experienced prize designers in government and philanthropy, as well as a proprietary database of over 400 challenges from Challenge.gov and select philanthropic, state, local, and international competitions. The result is a rich compendium of practical guidance for prize designers in the United States and around the world.

Public sector challenges by the numbers

THESE data summarize and characterize mainly public- and philanthropic-sector prize activity based on the analysis of 314 challenges found on Challenge.gov and validated through a secondary dataset of 89 philanthropic, state, local, and international challenges. In coding this data, we found that individual challenges often sought to achieve simultaneously more than one of the six outcomes discussed in this report. Our analysis of challenges by outcome illustrates how prize designers are prioritizing the elements of prize design to achieve certain results. Additional information on our data analysis methodology can be found in Appendix B.

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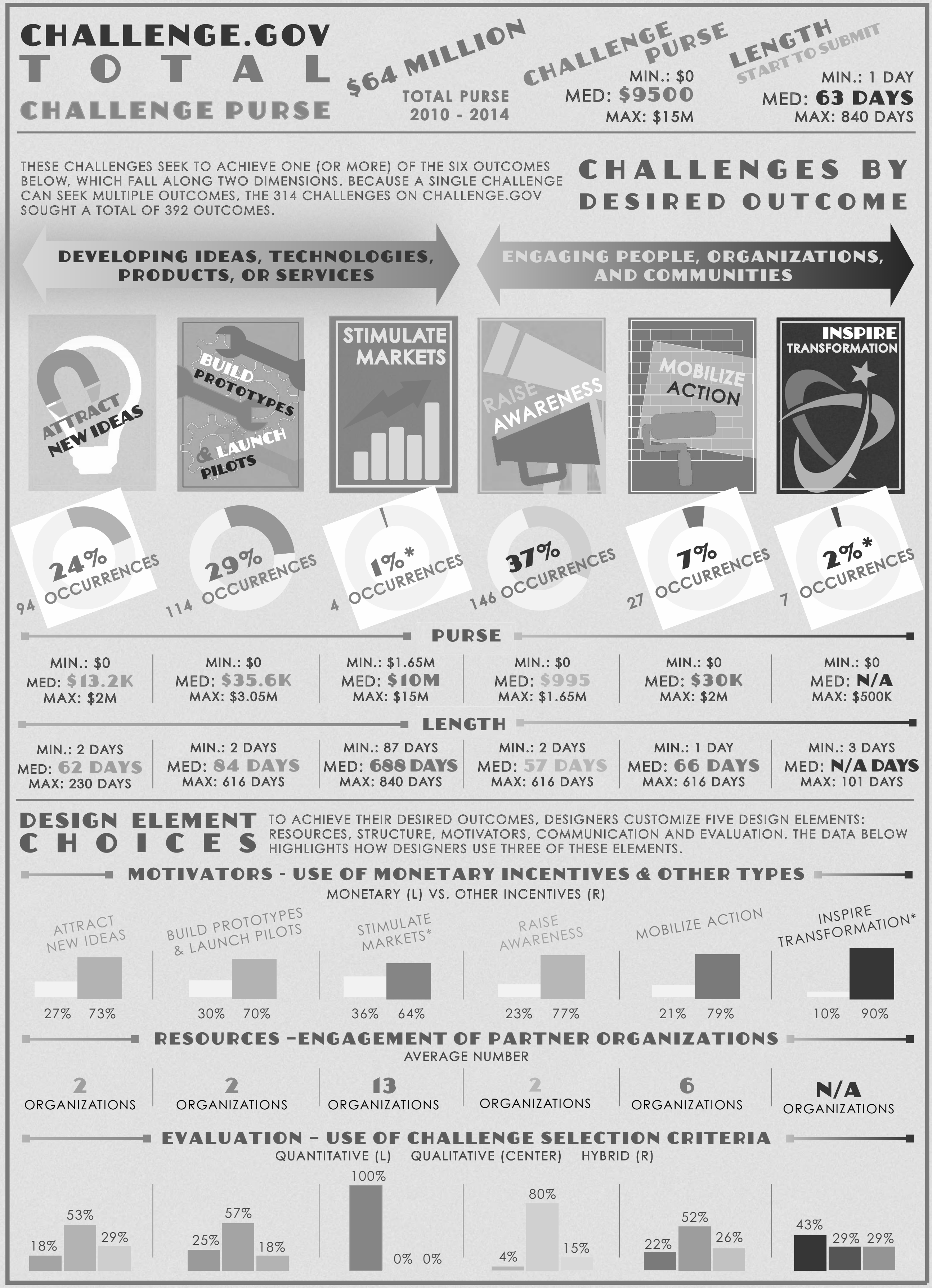
Figure 1. Public sector challenges by the numbers



*Because prize designers seek this outcome infrequently, this data is mostly anecdotal

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Getting started with incentive prizes

PUBLIC, private, and philanthropic leaders are wrestling with technological, economic, environmental, and societal problems that seem to get more complex each day. Public leaders, moreover, must consider these multifaceted problems with limited resources that often prevent them from developing innovative solutions quickly and effectively. This is why government leaders in particular are turning to incentive prizes to advance their missions through incentives and the ingenuity of the crowd.

Leaders who use prizes effectively take a strategic approach. They work with colleagues, partners, and subject-matter experts to carefully *select and define problems* likely to be solvable through prizes. They collaborate with stakeholders inside and outside their organizations to *determine the outcomes* they wish to achieve—and then use those decisions to drive a prize design process that will yield specific outputs. Because public organizations must adhere to specific legal requirements, government leaders determine what *legal authority* will allow them to achieve their desired outcomes. These leaders *publicize the challenge*, its requirements, and its results in language that will resonate with the audiences they seek to engage. Finally, to realize the full benefits of the prize, leaders initiate legacy activities to provide resources and support to the prize participants who remain engaged after the challenge comes to a conclusion.

Problem definition

Because problem definition involves grappling with a great deal of ambiguity, it is arguably the most difficult part of prize design. It sounds deceptively simple: What problem should the challenge address? Answering that question, however, requires clarity about *the outcomes sought and the ways to achieve them* as well as a *specific problem statement* that succinctly describes the fundamental difficulty to be overcome. Designers often initiate these definitional discussions with a diversity of internal and external experts and stakeholders, because they can bring valuable perspectives and ultimately need to be aligned around the final problem statement.

To manage the ambiguity of problem definition, designers often start by developing a clear understanding of the outcomes they seek and the different ways they can achieve them. Because prize design varies, sometimes dramatically, depending upon the outcomes selected, careful definition of these outcomes is critical. These early-stage problem definition discussions help to establish the causal and logical linkages between the specific difficulty to be addressed and the outcomes selected. They help to surface the kinds of challenges (for example, incentive prize, grant, investment) that are best suited to address the problem. These discussions reveal ways in which the designer's organization may or may not have the legal authorities, resources, skills, and capabilities to address certain facets of its own problems. Finally, by refining their understanding of the outcomes sought and ways to achieve them, designers can explore whether a prize is likely to produce results more effectively than other possible approaches.

Outcome specification establishes the broad set of aspirations, whereas problem statement definition more narrowly frames the need that the prize will ultimately address.

Developing a problem statement helps designers craft a need that is not too hard (because no one will win the prize) and not too easy (because the prize will be won too quickly and not necessarily with the optimum solution). Prizes need a problem statement that will be attractive to a broad selection of potential competitors (because greater diversity can lead to more innovative solutions), but not too broad (because an overly broad net can erode submission quality). And, the problem statement must describe a challenge whose scope is appropriate for the types of participants sought: A problem that requires years of work to solve or specialized facilities or high capital expenditure may not fit well with certain target participant groups.

Making these decisions often requires tapping into different types of expertise and devoting a considerable amount of staff time, depending upon the complexity of the problem. Technical experts can be valuable for grappling with the science and technology underlying the problem. Academics and industry representatives can be highly useful for evaluating the time, expertise, and expense needed to solve certain kinds of problems. Designers and strategic thinkers can help refine and reframe problems in ways that are conducive to prize-based solutions. Finally, a gifted facilitator can help to ensure that these different types of professionals have the right conversations and make progress toward a workable problem statement.

All manner of problems may be amenable to prize-based solutions, if defined properly. Consider, for example, the range of problems defined by USAID for its Tech Challenge for Atrocity Prevention. For one of the five components of this challenge, USAID defined the "problem" as *third parties who enable or contribute to genocide, consciously or inadvertently*. To solve this problem, they sought technologies and innovations that "identify, spotlight, and deter" these enablers. For another component of the prize, USAID identified the *unpredictability* of genocide as the problem. This led the agency to seek algorithms that could forecast potential hot spots based on sociopolitical indicators and historical trends.[8]

According to Jason Crusan, who directs the National Aeronautics and Space Administration's (NASA) Center of Excellence for Collaborative Innovation (CoECI), problem definition entails "hav[ing] to deconstruct the problem into bite-sized pieces, and abstract[ing] [each] to understand how it's just one piece of the larger puzzle."[9] Indeed, it can take up to a year to wrestle with problem definition.[10] During this time, designers typically conduct a detailed landscape analysis, meeting with internal and external experts as well as partners to define and digest the scope of knowledge applicable to the problem and its surrounding issues. As designers begin to prioritize specific areas of the problem for research, they can also begin evaluating what combination of potential solutions may best achieve their desired outcomes.

An example from CoECI emphasizes this point. Every year, fraud, waste, and abuse in the health care industry accounts for hundreds of billions of dollars in losses.[11] The US Centers for Medicare and Medicaid Services (CMS) wanted to apply new tools to their ongoing efforts to address this challenge. The agency partnered with CoECI, the state of Minnesota, Harvard Business School, and TopCoder to find a more efficient and effective way to help states spot medicaid fraud.

Given the challenges associated with identifying fraud, the partners took time to define the problem, which focused on how current software systems could not effectively screen risk scoring, validate credentials, authenticate identities, or sanction checks. To tackle this problem, they launched the Provider Screening Innovator Challenge, which sought screening software that could help ensure that medicaid funds are not spent fraudulently.[12] To make sure the overarching challenge would generate a workable solution, the design team broke it into four components and 124 separate challenges. As a result, the partners were able to obtain an ecosystem of solutions based on submissions from more than 1,600 participants

from 39 countries. The software applications developed as a result of the challenge series are being compiled into an open-source solution for the state of Minnesota—and perhaps the nation.[13]

Push versus pull: Is a prize appropriate?

Problem definition discussions inevitably raise important questions about which approach—a challenge, a prize or some other mechanism—can generate the best solutions. Experienced prize designers have learned that incentive prizes are not appropriate for every type of problem and are not a silver bullet even for the right problems. One valuable way to navigate this strategic choice is to consider the distinction between "push" and "pull" mechanisms, a reference to how different types of rewards, placed at different points in a solution development process, can create unique incentives.

- **Push mechanisms** include traditional grants and contracts, such as fixed price or time and materials contracts or research and development grants. These provide vendors or grant recipients with payments or incentives to develop and deliver specific services or technologies, in effect paying for the *effort* involved, but leaving the risk that the product may not meet expectations. Push mechanisms can be used to generate a range of outputs, from purchasing services or technologies that are well-understood to supporting early-stage research and development efforts that have uncertain outputs.

- **Pull mechanisms, including incentive prizes**, reward participants not for their efforts per se, but for their *outputs*, such as ideas, prototypes, pilots, or commercial products and services. Leaders use pull mechanisms to encourage participants to experiment with innovative and, sometimes, risky approaches, while paying only for results that meet predetermined rules

WHEN SHOULD YOU *NOT* USE A PRIZE?

Prizes cannot solve every type of problem. Here are a few considerations:

Prizes should not be used when there is a clear, established, effective approach to solve a problem.

A prize's strength comes from its ability to incent participants to create novel solutions. Using a prize to create solutions already available in mature markets may simply waste participants' efforts.[14]

Prizes should not be used when potential participants are unwilling or unable to dedicate time and resources to solve the problem.

For instance, as appealing as start-up companies may be as prize participants, they are rarely able to shift their commercial focus to a challenge. Prize designers need to understand the risk tolerance and capabilities of their potential participants before committing to the use of a prize that requires their engagement to be successful.

Prizes should not be used when there are only a limited number of participants who can address the problem.

If the universe of participants is small and known, then a prize may not be necessary. Instead, leaders should use other types of challenges, such as "pay for performance" approaches that issue grants or contracts with milestone-based payment terms. One example of this approach is NASA's Commercial Orbital Transportation Services program in which industry agreements with certain companies provide for fixed-price payments only when performance milestones are met.[15]

or specifications. For some pull mechanism prizes, if no one wins, the sponsoring organization is responsible for only its administrative costs.

Experienced designers often combine prizes with push mechanisms to achieve their goals more quickly and effectively. For example, in 2013 the Army Research Laboratory ran five prizes that successfully identified new methods for generating energy from a walking hiker and new ways to produce potable water for humanitarian missions. The winning solutions came from individuals from around the globe—many of whom would have not had the opportunity to work with the army through other means. The Army Research Laboratory plans to continue developing these ideas through traditional push mechanisms such as testing at laboratory facilities and future small business funding opportunities.[16]

Despite the fact that extensive consideration may be required to determine the suitability of a prize, this preparatory requirement has not put a damper on experimentation in the past five years. Many agencies, such as NASA, embrace prizes and translate their growing confidence and experience into policies that codify and explain their problem-solving strategies.[17] The White House Office of Science and Technology Policy provides annual progress reports on prize competitions offered by federal agencies, and the Office of Management and Budget offers detailed legal guidance to prize designers. This work can be immensely helpful for less experienced organizations considering similar approaches.

Experienced designers often combine prizes with push mechanisms to achieve their goals more quickly and effectively.

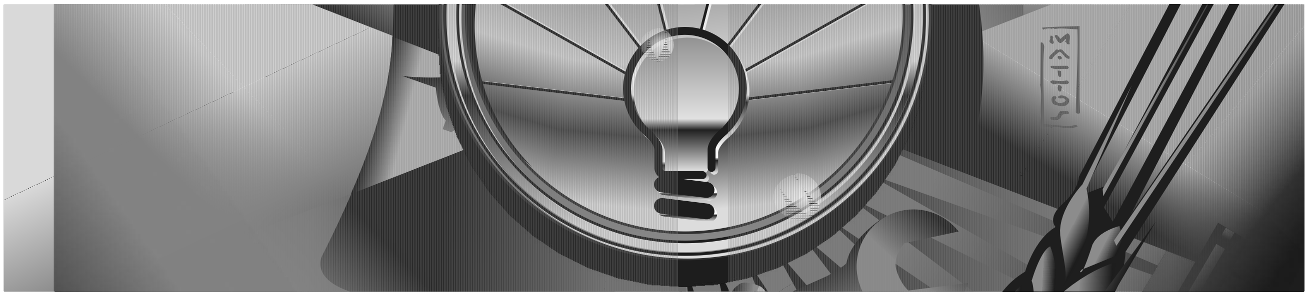
Most experienced designers consider prizes to be just one important problem-solving approach in a larger portfolio that includes challenges and other, traditional approaches as well. In some cases, for example, NASA program managers have folded challenge outputs into grants or in-house R&D efforts. In other cases, the agency uses traditional contract arrangements to implement designs solicited from prizes. NASA's designers view push and pull mechanisms not in isolation, but in varying combinations custom-designed to achieve their desired outcomes.[18]

Evaluating legal options

Public sector leaders can't simply design and execute a prize without first evaluating their legal authority to do so, particularly when it involves paying cash to winners. US government prize designers, in particular, must look carefully at the legal constraints they face. Typically, this involves early liaison with general counsel to avoid unwelcome surprises.

For federal agencies, several laws can affect incentive prizes. The most well-known is the America COMPETES Reauthorization Act of 2010, which provided broad authority for every federal agency to conduct prizes in the service of their missions. America COMPETES created a clear, simple legal path for using these tools and complemented other preexisting agency-specific prize authorities.[19] One key aspect of the prize authority provided by America COMPETES is that federal agencies are able to co-fund prizes (both the prize purse and administration costs) with other agencies as well as private sector and philanthropic organizations.[20]

In 2010, the Office of Management and Budget issued guidance on various legal authorities and provisions, intellectual property considerations, and other issues affecting prizes in a memorandum called "Guidance on the use of challenges and prizes to promote open government." This memorandum



provides prize designers and their legal counsel with a useful starting point for developing their own legal strategies.[21]

Building a legal strategy applies to state and city prizes as well, because legal requirements must be considered in light of desired outcomes. For example, designers of the New York City Big Apps Challenge intended to spur the development of tech businesses and therefore opted to let participants retain the intellectual property rights of the apps they created.[22]

The conclusion of a prize also poses legal considerations that should be addressed early in the design phase. Perceptions of faulty evaluation criteria or unfair judging procedures can lead participants to take legal action, especially if the stakes are high. Committing to the transparency of the judging process and ensuring that participants can view scoring and selection criteria when they register for the prize can ameliorate such issues.

In the federal context, the Government Accountability Office recently ruled that it did not possess the legal authority to adjudicate a dispute related to a prize offered by the Federal Trade Commission, despite its well-established ability to do so for contracts.[23] This ruling raises important questions about how the federal government will handle prize-related conflicts in the future.[24] It also underscores how important it is for prize designers to build prizes that are highly transparent, with independent judging panels and, for worst-case scenarios, conflict resolution processes.

After reviewing these considerations and engaging in an iterative problem definition process, designers will be ready to begin building a prize.

Linking prize outcomes to prize design

Prize design elements: Definitions

Designing a successful prize can be a daunting task. No one formula is adequate because each prize addresses a unique problem and set of potential participants whose incentives must be carefully understood.

Many public organizations do not possess all of the skills and capabilities needed to design an effective prize, such as online platform development or marketing expertise. In some cases, the necessary abilities involve distinct and highly specific insights into market dynamics or participant incentives. And in almost all cases, designers need help with problem definition, because a poorly defined problem statement can make it extremely difficult to achieve the desired outcomes.

Despite the unique nature of each problem, designers can rely on certain common elements. These can be thought of as ingredients, combinable in various ways to design prizes that generate specific outcomes. All of the elements matter, together forming an integrated and often complex set of strategic choices. How designers assemble and use them is at the heart of prize design.

There are many ways, for example, to craft a communications strategy to draw the attention of potential participants to a prize. But who should develop the communications campaign and its messaging? What channels should be used? How much time and money can be spent on the campaign? How can we measure its success? These are just some of the questions that designers must answer.

The strategic choices involved in challenge design can be grouped into five core design elements:

- **Resources**: Funding, labor, open datasets, online platforms, testing protocols, facilities, and partnerships—the infrastructure of the prize

- **Evaluation**: Selection criteria, judging protocols, and winner selection as well as measurement of the prize's impact and long-term legacy

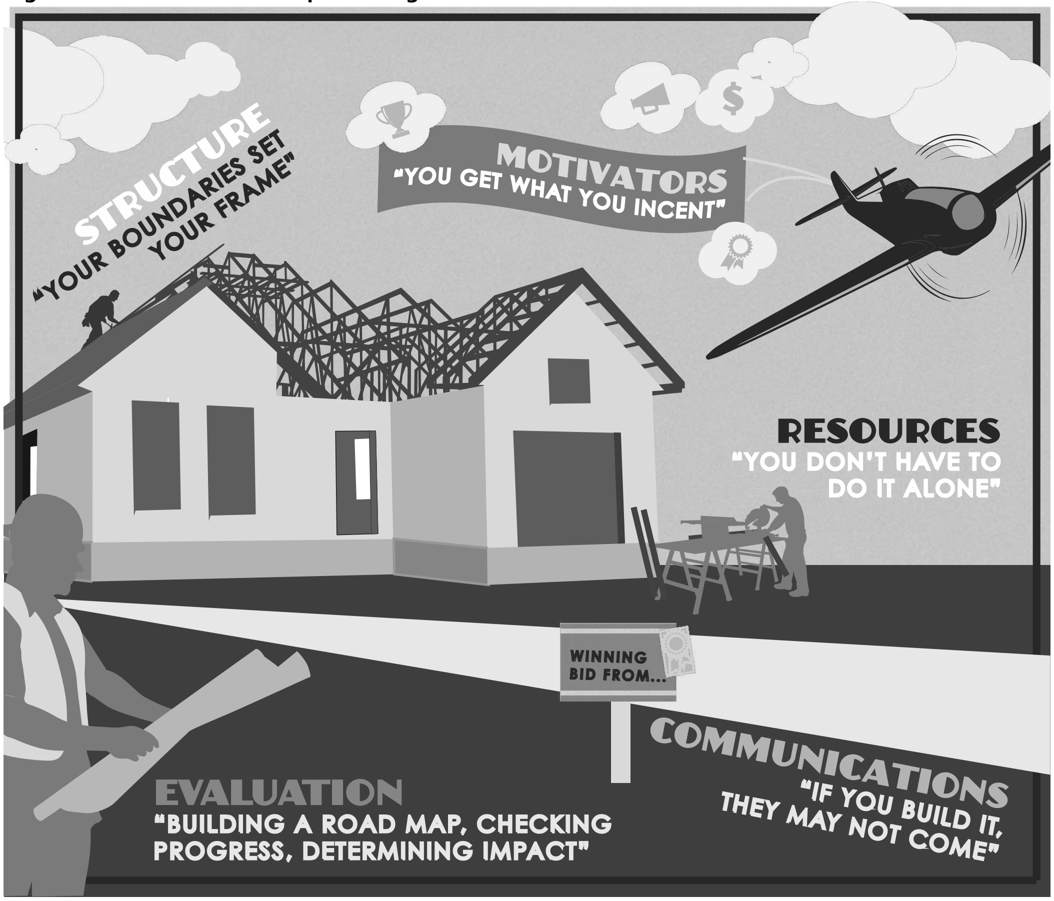
- **Motivators**: Cash purse and other nonmonetary incentives that can attract and reward participation, such as mentorship, collaborative opportunities, public recognition, validated performance data, and exposure to experts and luminary judging panels

- **Structure**: Rules that shape the prize's operations, classes for different types of participants, eligibility requirements, intellectual property requirements, timeline, stages, and other parameters

- **Communications**: Marketing and stakeholder management methods used to reach potential participants and partners and to raise awareness of the goals, progress, outputs, and outcomes of the prize

Designers consider these elements of prize design from the very early stages of problem definition to the period after the prize concludes, when sustaining participants' energy and focus can significantly help to achieve outcomes. Below we discuss these elements and

Figure 2. The architecture of prize design



Graphic: Deloitte University Press | DUPress.com

feature examples of how designers use them to create, implement, and ensure the legacy of their prizes.

Resources—You don't have to do it alone

There are four critical resource phases: design, implementation, award, and post-prize "legacy" activities. Depending on the desired outcome, these phases can be quite variable in terms of length, cost, and demand on resources. They can involve a few or many small contracts for vendor services as well as different types of partnerships. Most importantly, as each of these phases unfolds, designers learn a wealth of new information about what successful execution will require, with inevitable impacts on resource requirements and timing.

One major resource requirement, of course, is funding for the *purse*.[25] Since the purse is often relatively small, it can be tempting to view prizes as less-expensive alternatives to more traditional grants and contracts. Even if no one wins the prize, however, its *administration costs* can be substantial, particularly if the goal is to achieve outcomes that could require significant commitments to marketing, mentorship, and networking. LAUNCH, for example, a global challenge led by NASA, USAID, the Department of State, and NIKE Inc., is intended to identify and support innovative work contributing to a sustainable future. The initiative focuses on spurring collaboration among innovators; it offers no monetary incentives, but instead invests its resources in helping participants develop and scale their solutions.[26]

Furthermore, prize administration involves significant costs that fall into different categories including, but not limited to, labor, technology platform, marketing, events, travel, and testing facilities.[27] It requires a diverse set of abilities and experiences, obtained in-house or through in-kind support from partners and paid vendors. Each designer must define the right mix of in-house and external support by first assessing the organization's abilities.

Labor costs are involved in developing prize rules, advertising the prize, connecting with participants, administering interactions among stakeholders, judging entries, and evaluating the success of the prize after award. These activities will require a diverse team, with subject-matter experts to develop, advertise, and judge the prize, and experienced administrators to run it.[28] Effective designers should consider the labor resources required for each phase of the prize, such as estimating the number of potential submissions to ensure the availability of a sufficient number of judges. Bloomberg Philanthropies' Mayors Challenge, for instance, assessed how many submissions it might receive by sending RSVP cards to potential competitors.[29] The challenge also planned for and included labor costs that extended beyond award to establish a lasting legacy for the prize. For example, post-award coaching, technical assistance, and networking were provided in order to continue to spur action following the award.

The technology *platform* used to facilitate certain prizes also represents a major cost, as well as a critical component for success. Such online platforms can help target the right audiences, enforce rules, and standardize submissions. NASA's Mapping Dark Matter challenge, for instance, sought an algorithm for mapping dark matter, an elusive task that has stumped astronomers for years. NASA partnered with the online challenge platform Kaggle, using its leaderboard feature to offer an environment allowing data scientists and mathematicians to collaborate and compete. Kaggle's platform enabled the creation of a specialized community that ultimately included 73 teams. Within 10 days, a doctoral candidate in glaciology from Cambridge University had built an algorithm that outperformed NASA's existing one.[30] When considering different platforms, designers can evaluate a few key cost elements such as platform access fees and design consulting.[31] Appendix D offers more information on online challenge platform vendors.

Additionally, certain administrative costs may be directed toward activities to improve or strengthen submissions, including standard, accessible data, consulting/coaching support, and testing facilities. For example, a number of US government agencies have provided easy access to data and data standards for developers to improve entries in apps challenges such as DOE's Apps for Energy and Apps for Vehicles challenges.[32] This support structure was provided more directly in the Progressive Insurance Automotive X PRIZE where semifinalist teams were given vouchers for consulting services from private consulting firms and national laboratories in order to allow participating teams to improve their designs.[33] Testing facilities are also resources that many participants will not have access to when developing their prototypes; the provision of these places will help to improve and iterate participant designs in a laboratory setting. For example, the US government has been a key source for providing these facilities. In the Wendy Schmidt Oil Cleanup X Challenge, a Department of Interior testing facility was used to host physical and laboratory testing of finalist prototype designs for high-performing oil cleanup equipment, and in the Progressive Insurance Automotive X PRIZE, the Argonne National Laboratory provided dynamometer testing of the super-efficient finalist vehicles.[34]

Because prizes are still relatively novel, designers must often commit resources to *mobilize their own organizations*. Most champions are senior executives, but they can be other employees who have the networks and political capital needed to generate momentum. Champions can clear away significant internal barriers by clearly communicating to employees how solutions derived from the prize will

Because prizes are still relatively novel, designers must often commit resources to *mobilize their own organizations*.

supplement and support those developed within the organization.

Finally, designers should expend resources to find *partners* that can help fund prizes and play various strategic roles in execution. Many designers carefully assess their own internal capabilities to understand the kind of partner support they may need. As categorized by Raymond Tong and Karim Lakhani, partners can play a variety of roles across a spectrum: a "host" who develops and oversees the prize, a "coordinator" who solicits others to develop operational components, or a "contributor" who assists the hosts wit these tasks.[35] For example:

- **Host**—Ashoka Changemakers has teamed up with the LEGO Foundation to seek educational innovations through the Re-imagine Learning Challenge. The challenge is hosted on the Ashoka Changemaker website and uses its infrastructure. The three-year partnership includes a pledge of more than $200,000 from LEGO Foundation to support the challenge.[36]

- **Coordinator**—Humanity United convened the Partnership for Freedom, with sponsors including the White House, the Department of Justice, the Department of Health and Human Services, and the Department of Housing and Urban Development. This partnership launched Reimagine: Opportunity, the first of three challenges designed to improve the support infrastructure for survivors of modern-day slavery, resulting in more than 160 applications and 12 highly innovative solutions.[37]

- **Contributor**—The UN Development Program provided funding and guidance to Nesta for a challenge focused on developing sustainable, cost-effective, off-grid renewable energy supplies in rural Bosnia and Herzegovina.[38]

Many designers believe that partners from the private, public, and philanthropic sectors can help unleash the full potential of prizes.[39] For example, the Hurricane Sandy Task Force launched Rebuild by Design, a multi-stage challenge to create designs that increase the resiliency of those regions affected by Hurricane Sandy. The challenge administration involved a mixture of partners from federal (Department of Housing and Urban Development, National Endowment of the Arts), academic (New York University Institute for Public Knowledge), and non-profit (Regional Plan Association, Municipal Art Society of New York, and Van Alen Institute) organizations. The $2,000,000 purse was funded entirely by the Department of Housing and Urban Development's philanthropic partners, led by the Rockefeller Foundation. Through this integration of partners, the challenge resulted in the participation of 148 teams from more than 15 countries. Ten finalists received $200,000 and met with community leaders and stakeholder groups to receive feedback and compete for the opportunity to implement their designs.[40]

When selecting partners, designers often consider a number of factors, including what control may be ceded to partners in prize administration, and how their brands and support can help the prize succeed.

Evaluation—Building a road map, checking progress, determining impact

Evaluation includes a broad set of assessment and measurement activities that occur during every stage of a prize. It involves the initial determination of whether it is likely to be effective and appropriate, assessment of the quality of implementation processes, development of the criteria and mechanisms used to select winners (including providing feedback to participants during and after the prize), and evaluation of impact and overall value. Proper evaluation is critical because it can affect whether participants view the prize as fair, shape the validity of the results, and, thus, ultimately determine its success. Effective evaluation is also an essential input to strong prize management, both to improve implementation processes and to inform decisions about whether to use a prize again.

In the early stages of design, there are two useful evaluative techniques. The first, sometimes called "theory of change," involves identifying how the prize, through its structure, rules, and activities will incent participants to engage in the behaviors that will help solve the defined problem. For example, a monetary reward may prove to be a stronger incentive for some participants than the opportunity for professional networking or coaching. This is also a good time to determine how prize-generated incentives may be influenced by the external environment (that is, incentives from other domains, such as the market) and other interventions, such as previously existing challenges seeking similar outcomes.

Second, using research and logical analysis, it is important to check whether *the planned challenge activities and outputs are likely to achieve the desired outcomes*. This evaluative technique includes identifying other factors that would be likely to help or hinder the achievement of these outcomes. The major benefit of this early assessment is that the design can still be changed to address these factors, including adding activities to reduce risks or reinforce positive outputs, such as adding additional elements of a broad program that supports scaling up once the prize has identified winners. To properly evaluate the prize, designers should develop indicators consistent with their theory of change for the prize's activities, milestones, outputs, and outcomes.

The *quality of the implementation processes* should be evaluated during and after the prize to determine whether discrete activities were actually successful. For example, some designers undertake special efforts to identify participants with particular characteristics. In some cases, this recruitment involves finding participants with specific technical expertise; in others, the goal may be to engage new and diverse individuals and organizations in the problem-solving space. In all cases, capturing good information about these processes during implementation can guide efforts to iteratively improve engagement activities for the current prize and provide insight into more effective engagement efforts for future prizes. Similarly, evaluation should include looking for patterns of who initially engages but then drops out or fails to continue through several rounds. It may be that the prize needs to be redesigned to provide additional support or that the current process is effectively winnowing out those who are unlikely to provide useful ideas or results.

A unique element of evaluation in prizes is *defining the criteria used to select winner(s)*. In creating these criteria, designers are shaping how participants will work, preventing unintentional and undesirable outcomes and curbing potential fraud. Appropriate selection criteria are grounded in and consistent with the overarching view of how the prize will generate change or solve a problem. Because the wrong criteria could lead participants to submit solutions that do not actually address the fundamental problem, designers often review their selection criteria repeatedly, working with internal and external stakeholders to anticipate and account for all possible responses.

One helpful practice for designers to follow is to open up draft rules for a period of public

One of the important elements of high-quality evaluation is to revisit the criteria at the end of the prize and assess whether they were appropriate.

comment, as was done by USAID recently for its potential challenge for desalination technologies, by the Department of Energy for its potential challenge on home hydrogen refueling technologies, and by NASA for its various Centennial Challenges.[41]

Designers should also carefully consider whether to use *quantitative* or *qualitative criteria*, or a mix of both. The Department of Defense's HADR challenge, which seeks a kit for use in humanitarian assistance and disaster relief, sets specific quantitative criteria for acceptable solutions—weight of less than 500 pounds, constant one-kilowatt power production, production of 1000 gallons of water per day, and so on.[42]

When quantitative criteria are not applicable or relevant, clear parameters and appropriate evaluation arrangements become even more critical. In the case of the Prize for Community College Excellence, the Aspen Institute needed to find a way to evaluate qualitative data about US community college performance. To make this process as rigorous and independent as possible, the institute employs a third-party evaluator that specializes in evaluation criteria framework design and in collecting and analyzing such data to ensure a strong basis for evaluation.[43]

To ensure validity and objectivity in the evaluation process, designers should determine who will *judge submissions*. Expert judging can be effective when the desired solution is highly technical, while crowdsourced voting is valuable when the goal is to engage public participation.[44] Some organizations have begun to examine how crowdsourced selection can lead to viable solutions. For example, DARPA's Experimental Crowd-Derived Combat-Support Vehicle Design Challenge solicited vehicle concepts from the public for different missions. The challenge also sought to examine the question, "How could crowdsourced selection contribute to the goals of defense manufacturing?"[45] While crowdsourcing the evaluation of winners can work and, at the same time, draw publicity, expert judging provides two distinct benefits. Judges with particular domain expertise can lend credibility to the challenge results and can improve submission quality through formal and informal feedback, if it is built into the prize structure.

One of the important elements of high-quality evaluation is to revisit the criteria at the end of the prize and assess whether they were appropriate: Did they lead to the selection of the best winning solution(s)? If the winner did not perform well, and some unsuccessful participants seemed stronger, it might be that the criteria were not right or were not operationalized correctly. For example, if simple weighting is used to derive an overall score, a proposal which scores badly on one criterion and well on another might end up the winner overall, even though it was inadequate in a vital area.

Another major component of evaluation is *measuring prize impact*. Designers should develop measurable indicators of success before launching the prize. Without these indicators and corresponding impact evaluation approaches, the prize may conclude without producing a clear understanding of whether it achieved or at least advanced the organization's goals, which can be disheartening to participants and designers alike. Thus "evaluability" should be an explicit objective of prize design.

Developing measures of success during the design phase can be helpful in several respects. It reinforces discipline in the design team to ensure that design elements link to desired outcomes. It shows skeptical stakeholders that the prize's effectiveness can be gauged objectively. And it assists the organization in assessing its overall return on investment. In anticipation

of end-of-prize impact evaluation, measures of success can be deployed for intermediate outcomes, such as milestones for building prototypes or website page impressions for raising awareness. In addition, designers can evaluate other important intermediate outcomes, such as strengthening the community of participants, improving their skills and knowledge, and mobilizing capital on their behalf.

Because measures of success can be both quantitative and qualitative, effective evaluation will typically include systems to gather both kinds of data systematically and also capture unexpected data, such as wider impacts of the prize process. Common approaches include:

- **Measuring funds leveraged**. The MIT Clean Energy Prize, for example, distributed $1,000,000 to its winning teams. The teams were asked to develop business plans for the prize and submissions generated $85,000,000 in capital and research grants.[46]

- **Comparing outcomes with alternatives**. The Talent Dividend Prize sponsored by CEOs for Cities and the Kresge Foundation, for instance, supports college graduation with a $1,000,000 prize. The designers measured returns by comparing the results with the opportunity cost of four fully funded college scholarships. In this case, the prize produced more than four college graduates and was therefore judged a success.[47]

- **Assessing reach and influence.** For certain outcomes, such as raising awareness and mobilizing action, evaluation can involve tracking net new followers and activities undertaken by participants during and after the prize to build on what they produced. The EPA ENERGY STAR National Building Competition, Battle of the Buildings, used the "Biggest Loser"-style competition to save energy and reduce greenhouse gas emissions. To make their results more meaningful and measurable, the EPA asked participants to find creative ways to contextualize how much energy their buildings were saving. Some of these submissions went viral and grabbed the attention of Good Morning America and *The New York Times*.[48]

To create these metrics, designers should consider what evaluation indicators and measures can be collected during the prize (that is, media impressions or surveys of competing teams that collect information regarding dollars/hours spent preparing solutions), and what outputs and outcomes should be assessed in the months and years following the challenge (that is, follow-on investment, change in public opinion, market adoption, scale, and behavior change decay rate). The latter measures may require significant investment of time and resources during the "legacy" phase post-award. Designers should also note that getting post-award data from participants may necessitate building reporting requirements into the prize rules to enforce compliance or allow access.

The use of objective, third-party data such as government statistics can increase the credibility of the prize evaluation process, but in almost all cases it is necessary for designers to obtain new data. The Aspen Prize for Community College Excellence, for instance, first worked with a data/metrics advisory panel to develop a model for selecting the top 120 US schools. The institute then asked the eligible institutions to submit applications featuring data about how they were advancing student learning. Working in tandem with the data/metrics advisory panel, the institute organized and analyzed these data to determine winners.[49]

There should be an overall evaluation of whether the prize was worth it. This is not a simple matter of comparing the direct cost of running the prize to the value of the solution produced. In some cases, a prize might have been unnecessary, and the solution would have come about through other means. In other cases, the wider impact on participants who don't win, including those who go on to

develop new innovations because of what they learned during the prize, will be significant.

Measuring changes should not only be limited to positive impacts. Particularly for government agencies, there should be follow-up to explore whether there have been unintended negative impacts of the prize implementation. Return on investment calculations often leave out the wider costs incurred by other parties in the process. An overall "value for effort" calculation, taking into account positive and negative impacts on winners and losers as well as resources used by other parties, provides a more reliable and comprehensive view of the merit, worth, and value of a prize. In particular, such an analysis would be helpful in checking for wider potentially negative impacts—such as organizations becoming less inclined to participate in prizes because of the low return on their investment.

In addition to measuring the changes that have occurred, there should be some investigation of the extent to which change can be attributed to the prize. Experimental and quasi-experimental designs, involving a control group or comparison group of participants may be feasible in some circumstances, but they are unlikely to be cost effective or ethically acceptable given the human subjects that need to be involved. Instead, rigorous non-experimental approaches to causal attribution and contribution are useful to identify possible alternative explanations for the impacts, and whether they can be ruled out.

These various approaches to evaluation need more than a few simple metrics to track. Designers need to think carefully about what they are trying to assess, when and how, so that they can surface the most helpful insights for their current and future prizes. Designers sometimes create independent teams to assess the success of their work, as illustrated by the Rockefeller Foundation, which uses an evaluation group to study the impact of its innovation projects.[50]

Motivators—You get what you incent

Motivators spur participation and competition. These incentives should encourage the right participants in the right ways to do the work required by the prize. Successful designers use motivators to increase the participants' return on their investments of time, effort, and resources.

The prize award itself is, of course, the most visible motivator, encouraging participation and channeling competitive behavior toward the desired outputs and outcomes. Historically, awards have included cash purses, public recognition, travel, capacity building (that is, structured feedback and skills development), networking opportunities (that is, trips to conferences), and commercial benefits (that is, investment and advance market commitments). Public sector challenges often feature diverse awards. At one end of the spectrum is the Department of Energy's L-Prize, which offers a $10,000,000 cash award and an advance market commitment to those who develop the next-generation light bulb. At the other end is the Department of Health and Human Service's Apps Against Abuse, which targets domestic violence and motivates participants with an award solely of a public winner announcement by government leaders.[51]

The size and type of award provides designers with important signaling effects and leverage opportunities. Designers typically try to ensure that the purse is commensurate with the magnitude of the problem, the types of participants required, the amount of time likely to be involved in reaching a solution, and the amount of media and public attention desired. Qualified participants are unlikely to compete if the prize offers a small purse but requires a year or more of effort on a hard problem. For prizes that require commercial participants, such as established companies or startups, the purse must be economically interesting in the sense that it could defray research and development costs, pay for certain types of risks and opportunity costs, or

provide something companies can highlight for branding purposes, such as third-party validated performance data or a "badge" marking the company's submission as successful in the prize. Large purses are also more likely to encourage the formation of new teams including both technicians, experts from relevant disciplines, and investors. For prizes seeking outcomes such as development of prototypes, pilots, or market stimulation, this element of design is critical because it helps designers attract outside capital.

Mentorship also can be a motivator and is used increasingly in prize design. Designers can incorporate mentorship in the prize structure, providing participants with access to experts, tools, leading practices, and other resources to accelerate the development of high-quality solutions and support the formation of communities of interest around the problem.[52] Participants do not need to win to benefit from this experience.

Some designers pair winners with industry leaders to drive post-award momentum. The Apps 4 Africa challenge, established by Appfrica (one of Africa's oldest acceleration programs), provides winning African technology entrepreneurs with mentors who help them with business development and product design. This mentorship has helped 11 new companies raise an average of more than $90,000 each in follow-on funding.[53]

Many designers are developing *collaborative environments*, enhancing knowledge sharing among participants by developing rules and evaluation criteria that encourage them to work together. Some intentionally develop opportunities for traditional participants to collaborate in problem solving, using virtual and in-person team summits and participant "bootcamps."[54]

But collaboration in prizes is not always useful. Intentional matchmaking among participants can be tempting, but it can also lead participants or observers to think the prize is fixed or that its administrators are interfering too much in the prize's outcomes. Furthermore, while collaboration may be appropriate for achieving certain outcomes, fierce competition can *also* be useful, particularly for shortening product development timelines. Designers should carefully evaluate this trade-off between collaborative and competitive motivations when thinking about the best path to a particular outcome. For example, if seeking a new prototype, the intensity of competition may need to be high to accelerate prototype performance on an aggressive timescale. If, however, the designer is seeking increased engagement among a population, then more collaboration may inspire others to begin participating in the prize.

Designers should carefully evaluate this trade-off between collaborative and competitive motivations when thinking about the best path to a particular outcome.

Finally, for certain outcomes, *intellectual property rights* can serve as a powerful motivator. The prize sponsors' degree of ownership over submissions is a key design consideration. Do they want to use the solution in a proprietary manner, require that solutions be made available to the public through an open source license, or just to have access to it in the marketplace? The options range from full retention of rights by participants to full retention of rights by the organization running the prize. One important consideration for US government leaders interested in stimulating innovation is how the America COMPETES authority protects participants' intellectual property.[55] Regardless of where the prize falls on this

spectrum, clear, upfront terms of ownership are critical. The rules for the US Air Force's Fuel Scrubber challenge, for example, clearly stated that winners will retain their intellectual property rights, signaling in advance that challenge participants can commercialize their winning solution and profit from it in the market.[56]

Structure—Your boundaries set the frame

Structure, or prize architecture, is the set of constraints that determines the scale and scope of the prize, as well as who competes, how they compete, and what they need to do to win. A competition period that lasts too long risks losing participant interest and one that ends too quickly may not give participants enough time to develop solutions. Winner-takes-all prizes can discourage participants with low risk tolerance. Those with well-defined phases and milestones can modulate competition, winnow participants at different stages, and reward only the most innovative solutions. Due to such considerations, successful designers devote significant time and effort to prize architecture.

Eligibility requirements shape the population of participants. Which participants should designers target—individuals, teams, organizations, established institutions, or even political entities such as cities or states? The choice involves at least two considerations. First, given the desired outcome, who is best positioned to solve the problem? Who has the right skills, resources, and interests? Second, if the desired outcome includes a form of engagement extending beyond the immediate pool of potential participants, how can they influence the larger community or stakeholder group? It is worth noting that in the case of challenges sponsored by the US government, participant eligibility is shaped by the authorities under which the challenge is administered.

The Georgetown University Energy Prize, sponsored by the Joyce Foundation, the American Gas Foundation, and the Department of Energy, among other partners, challenges communities "to work together with their local governments and utilities in order to develop and begin implementing plans for innovative, replicable, scalable and continual reductions in the per capita energy consumed from local natural gas and electric utilities."[57] This example provides insight into how designers can structure eligibility requirements to shape team formation and expand the influence of the prize beyond individual citizens.

Successful designers often try to define their prizes in ways that will attract the largest and broadest pool of participants, as the most innovative solutions often come from those without previous exposure to the underlying problem. Even when casting a wide net, however, designers should be careful about eligibility. For some, the quality of submissions is more important than their quantity, or resource constraints may dictate a smaller participant pool, making restricted eligibility the best choice. For others, the variety and sheer quantity of submissions that can be obtained from broad eligibility requirements are more desirable. Narrow eligibility requirements thus may be best for a prize seeking a handful of thoughtful concept papers about a technical solution, while broad requirements could be better for a challenge seeking a new logo design.

If multiple types of participants are desired, designers should consider whether a certain team profile increases the possibility of a successful outcome. Additionally, designers must think about whether different types of participants should compete in one pool or be separated into different categories. For example, the US FIRST Robotics Competition hosts four age-based classes of challenges for students aged 6-18: Junior FIRST LEGO League, FIRST LEGO League, FIRST Tech Challenge, and FIRST Robotics Competition. The FIRST Robotics Competition requires a minimum of 15 high school students and 3–6 professional adult mentors per team.[58]

Prize length typically consists of two time periods, those for submission development and for judging. The former requires designers to determine the appropriate time likely to be needed to reach a particular outcome. For example, the Case Foundation's Finding Fearless competition was focused

on generating ideas to solve chronic social challenges and gave participants only 20 days to submit their ideas. DARPA's UAV Forge competition, by contrast, gave participants 152 days to showcase a working prototype of an unmanned aerial vehicle.[59] Data on prize length is detailed in the following sections by outcome. Designers should note that the lengthier the prize, the higher the likelihood of administrative staff turnover. It is critical that designers document their rationale and assumptions behind key design decisions and desired outcomes for any potential staff transitions.

Designers often engage with subject-matter experts or potential participants to develop a realistic assessment of the time needed for solution development and the likely number of submissions. This information can also be used to estimate the appropriate number of judges needed to ensure a timely review. The selection of judges with the appropriate technical expertise and availability to commit their time for thorough reviews is critical for outcomes focused on developing prototypes and stimulating markets. Designers should estimate the time required for an individual judge to assess submissions or the time for a panel of judges to reach consensus on the relative merits of prize submissions, and use those estimates to determine the number of part-time judges needed. If the number of part-time judges becomes unwieldy for challenge administrators based on this approach, designers should consider compensating judges to receive full-time evaluation support.

Designers also consider various forms of *challenge segmentation* to encourage certain kinds of behavior. Dividing the challenge into rounds can allow participants to modify and improve their submissions, thus increasing their quality. As an example, the Institute of Justice's Ultra-High Speed Apps challenge has two phases, the first solely for the generation of the app ideas and the second for actual software development.[60]

Some designers segment their prize structure by *topic*, with multiple related sub-challenges taking place concurrently. This can increase the prize's impact by elevating the importance of certain topics and attracting a broader set of solutions. The EPA's Campus RainWorks Challenge, for instance, invites students to design an innovative green infrastructure project for their campus, offering two topic areas. One category involves designing a master plan for a broad area of campus; the other seeks designs for a smaller location.[61]

Designers can also segment prizes by *geography*, with simultaneous challenges in separate locations (such as state challenges leading to a national final round). The Strong Cities, Strong Communities (SC2) Challenge is a federal interagency initiative seeking innovative ideas to incent economic development. The challenges are customized to the areas they are designed to help: Las Vegas, Nevada; Hartford, Connecticut; and Greensboro, North Carolina.[62] Such a strategy can help manage larger-scale challenges and focus attention on site-specific solutions for targeted areas.

Communications—If you build it, they may not come

Communications serve several different strategic goals. They can attract participants, spur them to compete, and maintain their interest afterward. Also, communications keep partners and stakeholders informed about the purpose and progress of the prize, helping to secure their support and, in some cases, funding. For many designers, communications are also a mechanism for achieving certain specific outcomes, such as building market awareness of new capabilities or public enthusiasm for new behaviors that further the public good. Because communications are so important, designers should plan and invest carefully to build the right buzz.

Effective prizes use *robust branding* plans to build recognition and credibility among the participant and stakeholder communities. This can be achieved through press releases, social media, and targeted invitations, using the organization's and partners' networks where appropriate. During Bloomberg Philanthropies' Mayors Challenge, for instance, challenge administrators sent personalized invitations

to eligible cities outlining the challenge's importance.[63] Establishing a clear and powerful brand is critical to the post-award legacy of the challenge and will significantly impact the challenge's sponsors' ability to attract public attention and the desired participants to future rounds. Many broadly recognized challenges dedicated significant time and resources to building a lasting brand including but not limited to the Mayors Challenge, XPRIZE, and the NASA Centennial Challenge.

To build credibility, designers should *clearly publicize rules and evaluation criteria* and regularly update participants and stakeholders on the process. To facilitate these communications, external partners can provide expert advice and support. For example, Nesta has partnered with the UK Department for Business, Innovation and Skills and made use of their combined networks to market its Open Data Challenge Series to potential participants.[64]

Strong communications help designers to *manage relationships with participants and partners* during prize implementation. It's useful to create regular check-ins with participants and provide them with effective communication channels to discuss any issues that may arise. Check-ins also provide participants with feedback that can lead to more effective solutions. For example, the Department of Energy's National Geothermal Student Competition featured two phases. The first 30-day phase required an initial concept paper. Teams chosen for advancement were then required to participate in three biweekly review meetings and submit regular reports documenting their progress over the course of the challenge to ensure they were progressing toward a final product.[65]

Designers attempting to build communities or markets typically establish *post-award messaging capabilities*. This may involve periodic post-award webinars; publications summarizing lessons learned, data captured, and aggregate outputs from the prize; "road shows" to visit relevant conferences, agencies, legislators, and other stakeholders; and reunion conferences that encourage participants to discuss their progress or even online collaborative spaces. For example, the International Space App Challenge was a two-day "hackathon" that included 9,000 people who met at 83 locations as well as 8,300 remote participants. Together, they worked on 50 different NASA challenge topics and developed 770 solutions in the course of one weekend. After the global awards, local leads from each location facilitated the creation of Google Groups to serve as a medium for ongoing communication and idea sharing between the participants.[66]

Prize design outcomes

In the last five years, public sector prize design has become increasingly diverse and sophisticated, with a shift in focus from prize types to outcomes. In the past, the selection and use of a prize type, such as a "point solution" prize for new technology, reflected a somewhat rigid belief that prize types and outcomes should match exactly. As designers have become more comfortable and flexible in crafting prizes, they are finding that it is better to begin with the outcomes they want to achieve and then assemble the right mix of design elements to achieve them.

In this section, we examine the six key outcomes designers most often pursue as well as the prize design elements that are critical for achieving these outcomes. While designers should recognize that prizes usually require all five of the elements of design introduced above, we highlight those elements that are most important to get right to ensure that the prize achieves its intended outcome. We also know that many prizes seek and achieve multiple outcomes. Consider the MIT Clean Energy Prize, which distributed $1,000,000 to its winning teams. While the prize explicitly solicited business plans, it has *also* stimulated the market by generating $85,000,000 in capital and research grants.[67] Many advanced designers attempt to use prizes both to develop markets for a technology, good, or service *as well*

Figure 3. Getting started with the elements of prize design

Graphic: Deloitte University Press | DUPress.com

as to create social impact. Appendix A offers more detailed guidance.

Advanced prize designs can reach a range of actors. For outcomes aligned to developing ideas, technologies, products, or services, designers typically focus on the participants who are creating models or tangible items to achieve a particular outcome. For prizes aimed at engaging people, organizations, and communities, designers are generally concerned with participants as well as a *broader* audience that may include people, groups, organizations, or even institutions.

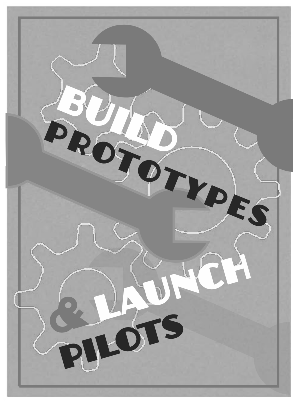
As designers work with the elements of design to build a prize, they also consider its legacy. Using prizes or challenges more generally to achieve certain outcomes requires taking the long view. Designers evaluate how a prize will work with other problem-solving approaches, which their organizations may be able to deploy. They make plans to engage participants and broader audiences after the prize concludes to reinforce key messages, branding, or desired behaviors. They build post-prize activities and foster networking and learning opportunities to help participants strengthen and refine the innovations that were incented by the prize. When designers want to simulate markets, they may develop a series of challenges that pull participants through different stages of the innovation process—first a prize to produce, test, and improve a model and then perhaps an advanced market commitment to help winning participants gain traction in an emerging market. Designers who ignore their post-prize legacy when trying to assemble the elements of design risk undermining their own desired outcomes.

Figure 4. Major outcomes for incentive prize design

DEVELOPING IDEAS, TECHNOLOGIES, PRODUCTS, OR SERVICES

SOLICIT CONCEPTS AND TECHNIQUES

Ashoka Changemakers' G-20 Small and Medium Enterprise (SME) Finance Challenge called for ideas on how public interventions can unlock private finance for SMEs across the world.



PRODUCE, TEST, AND IMPROVE MODELS

The New York City Big Apps Challenge drove software developers to create apps that increase the accessibility of municipal data.

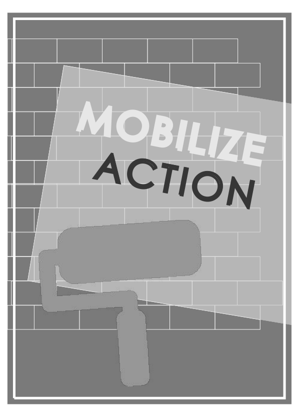
CREATE AND SCALE NEW MARKETS

The Progressive Insurance Automotive XPRIZE, supported by the Department of Energy, sought to reshape the automotive industry by incenting companies to create a new generation of viable, energy-efficient vehicles.

ENGAGING PEOPLE, ORGANIZATIONS, AND COMMUNITIES

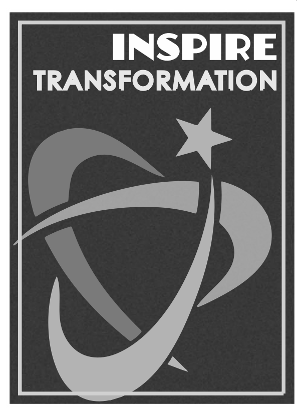
ENHANCE EXPOSURE AND EDUCATE ABOUT AN ISSUE

The Department of Health and Human Services (HHS) launched the "Stop Bullying Video Challenge" to help prevent and end bullying in schools and communities nationwide.



SPARK ENGAGEMENT AND BUILD SKILLS

The NASA Zero Robotics Challenge developed students' technology and engineering skills by having them develop the best algorithm to control robots on the International Space Center.



ORGANIZE FOR SUSTAINED CHANGE

The Aspen Prize for Community College Excellence sought to redefine "success" for community colleges to improve educational outcomes.

Graphic: Deloitte University Press | DUPress.com

Developing ideas, technologies, products, or services

Attract new ideas: Solicit concepts and techniques

Prizes allow designers to identify and expand on fresh, innovative ideas. They can focus the efforts and ideas of lots of different people with widely varying viewpoints on a broad range of public problems. The prize can gather existing ideas, expand existing ideas, or help create new ones, especially if new participants are brought into the solution space, given additional resources, or stimulated with new ideas and connections. As Michael Smith from the Corporation for National & Community Service and formerly of the Case Foundation put it, "Prizes give you a way to lift up an idea."[68] Idea outcomes may take the form of:

- Pithy taglines, such as the Federal Voting Assistance Program's Slogan Contest, whose submissions could not exceed 15 words[69]

- Theoretical concepts, such as the Department of Defense Humanitarian Airdrop Prize, which sought white papers on how to drop food and water out of planes safely and effectively[70]

- Actionable business plans and detailed technical design specifications, such as the Institute of Justice Body Armor Challenge, which sought 30-page technical approaches for testing the integrity of body armor[71]

In order to generate useful submissions, effective designers often provide participants with context about why they are seeking ideas and what they intend to do with them. For example, the Rebuild by Design competition administered by the Hurricane Sandy Task Force used a multistage challenge to attract design proposals that increase the resiliency of regions affected by Hurricane Sandy. The designers quickly and effectively solicited concepts and communicated the end goal of employing the solutions to rebuild the Tri-State area.[72] But, *caveat emptor*: The quality and workability of submissions will depend *strongly* on the selected design elements. The fundamental design challenge for this outcome is to strike the right balance between numbers of concepts and techniques solicited, processes used to review them, and plans for what happens to winning ideas.

Outcome benefits

- **Tap the wisdom of the crowd**: Prizes focused on attracting new ideas can allow organizations to quickly obtain new concepts from a broad community and provide a broad survey of possible approaches to solving a problem. As Guido Joueret of Cisco Systems explained, "We believed that by opening ourselves up to the wider world, we could harvest ideas that had far escaped our notice and in the process break free

BY THE NUMBERS
ATTRACT NEW IDEAS[73]

- Total prize purse *(n = 94)*
  - Minimum: $0
  - **Median: $13,250**
  - Maximum: $2,000,000
- First place prize purse *(n = 77)*
  - Minimum: $0
  - **Median: $5,000**
  - Maximum: $100,000
- Start to submission length *(n = 77)*
  - Minimum: 2 days
  - **Median: 62 days**
  - Maximum: 230 days
- 22% had multiple rounds

G-20 SME FINANCE CHALLENGE

Leaders of the G-20 countries in partnership with Ashoka Changemakers launched the Small and Medium Enterprise (SME) Finance Challenge to solicit groundbreaking ideas on how public interventions can unlock private finance for SMEs across the world.

Designers knew how these new ideas would be used after the challenge—the G20 countries created a $558 million fund to scale and support these new ideas. The short time period between start and submission (only 41 days) as well as a $1,000 early entry prize maintained momentum to increase the number of participants.

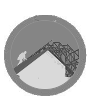
Challenge designers lined up eight well-respected judges to work through the 333 participant submissions. As a non-monetary reward, the challenge winners attended the G-20 Seoul Summit as well as an SME conference in Germany.[74]

from the company-centric ways of looking at technologies, markets and ourselves."[75]

- **Take a big challenge in small bites**: These prizes can be used to break a complex, ambiguous problem into smaller, less daunting parts. In some cases, prizes focused on attracting new ideas can help designers define the problem statement for a subsequent, bolder challenge.

- **Customize problem solving**: Prizes that reward ideas can be tailored for specific types of participants and problems. For example, the designer can use a broad problem statement, with open eligibility and robust marketing, to tap a large population of participants or opt for a specific problem statement with restricted eligibility to attract a highly skilled technical community.

Critical design elements



Structure—Select your competitors

Designers typically seek one of three types of participants: the public; a broad mix of expertise; or specialized, often scientific, communities of interest. This choice strongly influences the quality and diversity of participant submissions, with the risk that a mismatch between the problem and participant pool may generate few workable ideas.

To manage this problem, it can be helpful to use a technology platform associated with specific types of participants. Today, multiple online platforms can help facilitate and run prizes, such as InnoCentive, which solicits ideas from the scientific community, and Ashoka, which engages social entrepreneurs. Such platforms can tap into particular communities of interest, facilitate collaboration among participants, and support prize-related communications. (See Appendix D for a list of technology platforms.)

Evaluation—Determine how you'll use the idea

It's tempting to measure challenge success simply by the number of responses. While it's true that a large number of responses increases your odds of finding a good idea, the workability of those ideas is even more important. In the *Stanford Social Innovation Review*, Kevin Starr warns designers: "Most crowdsourced ideas prove unworkable, but even if good ones emerge, there is no implementation fairy out there, no army of social entrepreneurs eager to execute someone else's idea."[76]

The Air Force Research Lab (AFRL) provides a strong example of translating submissions into workable solutions. Specifically, AFRL challenges include submission

evaluation criteria that can be validated and further refined through laboratory testing with a focus on the ultimate use of the idea.[77] Additional examples for designers include criteria to evaluate the maturity of submissions, the speed at which the submissions can be developed into prototypes or pilots, and the cost and ease of implementing submissions given an organization's resource constraints.

Resources—Be prepared to assess submissions efficiently

Good designers typically match the anticipated volume of submissions with an appropriate number of properly resourced judges. Given the relatively low barriers to entry for prizes seeking ideas, however, the sheer volume of submissions can sometimes surprise and even overwhelm. Designers can forecast the likely number of submissions by examining trends from past prizes, surveying the potential participant community, and sending invitations requiring RSVPs to targeted groups.

To maintain credibility with participants and sustain interest in the prize, successful designers often seek to reduce judging time. Many employ a two-step screening process: a larger, less specialized staff conducts an initial review before passing on the most promising ideas to expert judges. This review process, however, must be transparent to avoid perceptions of unfairness.

Recommended design tactics

- **Standardize submissions and clearly weight judging criteria**: A common failure point of prizes seeking new ideas is unclear criteria for picking a winner. If judges must pick between apples or oranges, there is a higher risk that participants will dispute the results. In contrast, the FTC Robocall challenge made judging criteria especially straightforward. The three evaluation questions and corresponding weighting included: 1) Does it work? (50 percent), 2) Is it easy to use? (25 percent), and 3) Can it be implemented? (25 percent). To level the playing field with individual participants, the FTC developed a separate track for organizations with 10 or more employees.[78]

- **Use multiple rounds**: Prizes that focus on attracting new ideas increasingly feature multiple rounds to winnow the best submissions before final award.

- **Consider shorter and smaller challenges**: Prizes seeking new ideas typically employ smaller purses and shorter competition lengths than those seeking other outcomes. This is justifiable to participants due to the lower level of effort required.

- **Design the prize with the end use in mind**: Clearly communicating how winning ideas will be used can improve participation and spur participants to generate particular types of ideas. By linking ideas to the organization's larger mission, designers can build stronger, deeper, and more lasting connections with the communities that generate them.

Build prototypes and launch pilots: Produce, test, and improve models

For prizes seeking to build prototypes or launch pilots, the goal is not simply to generate an idea that addresses an important public problem, but rather to realize a *functional version* of a technology, product, or service, and sometimes test it with its intended customers.

Building prototypes or launching pilots often entails the creation of new technologies and can be particularly effective for shepherding them through late-stage research and early-stage development, a difficult part of the innovation lifecycle sometimes called the "valley of death."[79] For example, the My Air, My Health Challenge run by the EPA and the HHS spurred the creation of sensor prototypes measuring pollution's health impacts, but also

required participants to demonstrate how environmental agencies and individual citizens could put these systems into practical use.[80]

BY THE NUMBERS

BUILD PROTOTYPES AND LAUNCH PILOTS[81]

- Total prize purse *(n = 114)*
  - Minimum: $0
  - **Median: $35,644**
  - Maximum: $3,050,000
- First place prize purse *(n = 98)*
  - Minimum: $0
  - **Median: $15,000**
  - Maximum: $2,000,000
- Start to submission length *(n = 101)*
  - Minimum: 1 days
  - **Median: 84 days**
  - Maximum: 616 days
- For evaluation criteria *(n = 114)*
  - 57% of prizes used subjective criteria
  - 29% used objective criteria
  - 18% used a hybrid of subjective and objective criteria
- 14% of prizes used a leaderboard, and 12% were hackathons *(n = 114)*
- For motivators *(n=114)*
  - 86% of prizes used monetary incentives
  - 82% used recognition
  - 49% involved commercial benefits

This outcome is particularly attractive because it can provide access to a new range of useful products and services, while requiring the organization to pay only for those that meet its needs. Prizes leading to products have the added benefit of relatively quantifiable and objective metrics of success.

Designers focused on services can also require practical demonstrations of success. For example, in New York City, a School Choice Design Challenge recently asked participants to develop a new software application to help families select high school programs. If a winning app is selected, it will make it easier for New York City eighth graders to choose among more than 700 high school program options each year.[82]

An important consideration for designers focused on this outcome is providing participants access to facilities to test prototypes. The cost and logistical challenges of creating an environment to iterate upon solutions is a significant barrier to entry that can stifle innovation. Designers focused on this outcome should consider providing access to testing facilities in order to place the focus of participants on research, innovation, and ideally future commercialization.[83] For example, the Wendy Schmidt Oil Cleanup X CHALLENGE asked participants to develop solutions to clean surface oil from seawater. The challenge was valued at $1,400,000 and provided participants an opportunity to test their work at the National Oil Spill Response Research & Renewable Energy Test Facility.

Designers seeking to build prototypes or launch pilots should pay careful attention to problem definition as well as particular elements of design, such as *motivators* and *structure*. Expert designers can spend months in defining the technical problem, so that the prize is appropriately bounded. The Centers for Medicare and Medicaid Services's Provider Screening Innovator Challenge, which asked competitors to develop screening software programs to help ensure that Medicaid funds are not diverted from the most vulnerable Americans, required more than a year to

NEW YORK CITY—BIG APPS 2012

New York City's Big Apps Challenge sought innovative software applications that made municipal data more accessible to city residents.

Designers tapped into the developer community to access external expertise. They considered analogous challenges to help set the $50,000 purse. Designers broke the challenge into 10 topics (for example, green, health and safety, and mobility) and posted clear requirements for each category. They included commercial benefits, inviting investors such as BMW to help judge the challenge. Finally, New York City included an "Investor's Choice Winner" and allowed the grand prizewinner to demo the app at the New York Tech Meetup.

The Big Apps Challenge spurred the development of 96 apps using municipal data in new and innovative ways.[85]

develop and ultimately involved 124 "mini-challenges" to attract the right solutions.[84]

Motivators and structure also matter because prize designers need to ensure that they attract the right kinds of participants, and that those participants are encouraged to compete in the right ways. Designers will often carefully study the motivations of distinct participant groups, including startup companies, large corporations, and academics, to ensure the challenge appeals to those most likely to compete.

Outcome benefits

- **Develop new intellectual property**: Building prototypes or launching pilots can require significant time and money, especially when designers seek solutions that serve a public good, but are not attractive to commercial markets. Designers can overcome these barriers through a variety of incentives, including attracting investment capital, encouraging merger and acquisition activity, and building market awareness. One of the winners of the USDA's Healthy Apps for Kids challenge used the momentum of the prize to develop a commercial opportunity. The media coverage surrounding his winning solution led to a for-profit version, with partners providing licensing and advertising opportunities.[86]

- **Engage external viewpoints to test ideas**: A prize can be a valuable tool for organizations that lack the internal capabilities to develop a prototype or pilot. Such prizes allow public agencies to tap into a diverse array of experts, tinkerers, inventors, and investors to achieve results beyond their own means.

  Consider the daunting task of designing dexterous, yet durable gloves for spacewalks. In 2009, NASA's Astronaut Glove Challenge asked participants to improve space suit glove design to reduce the effort needed to execute tasks and improve the durability of the glove. Using a challenge allowed NASA to engage external participants to reimagine design and build a proof of concept.[87]

- **Clarify your requirements**: The design process for prizes that build prototypes or launch pilots can involve a broad community of potential participants (for example, companies, nonprofits, universities, and individuals), spurring them to examine technical requirements and determine the breakthroughs needed to achieve them. By defining success for a specific problem, prize designers can help a community of participants coalesce around critical technical or programmatic specifications.

Critical design elements

Resources—Be prepared with market analytics

Organizations often seek technical solutions unavailable in the commercial market. In these cases, prize development may require a relatively high operational budget to conduct a landscape review of immature market players, craft the problem statement, and design selection criteria. Partners that could make money from winning prototypes and are willing to invest in the prize can help cover some of these costs.

Motivators—Tailor the purse to competitor risk and market conditions

To set the purse appropriately, designers typically investigate the costs of solution development as well as the potential market value of the new product or service. This requires economic and market analysis, a capability many public organizations lack and therefore engage vendors to complete.

The purse does not need to cover the entire cost of development, particularly if outside investors are interested in supporting participating teams, but it does need to cover at least some of the risk participants assume. If only a small purse is possible, designers can supplement it with other non-monetary benefits, such as access to data, strong intellectual property protections, and introductions to venture capitalists. Remember, though, that commercial participants are unlikely to devote money or time to develop new products or services unless they believe they can sell them into an existing or emerging market.

Evaluation—Make sure the winner selection is unambiguous

The selection criteria for the winning submission should be quantitative, rigorous, and testable, particularly for prizes with a technological focus. In the course of prize design, it is helpful to develop, vet, and test criteria with outside experts and potential participants and partners to avoid having to revisit selection criteria during the course of the prize.

Recommended design tactics

- **Hold mini-challenges**: Challenges for new algorithms are common and are increasingly being split into measurable mini-challenges that build upon one another. These challenges often employ a contract with vendors, such as TopCoder, to administer the effort. These mini-challenges can be hosted on a single microsite, allowing participants to see how sequential milestones fit together. At the conclusion of the challenge, agencies can make use of the winning algorithm.

- **Use public leaderboards**: For longer challenges requiring rapid, iterative development, public leaderboards reporting participants' progress can create an increasing sense of urgency among teams while generating publicity. As one team comes closer to the required performance criteria, others increase their efforts and investments to catch up. For example, DARPA's Shredder Challenge focused on developing tools to piece together shredded documents and used a public leaderboard to display all participants and their points. DARPA periodically used press releases to announce the top teams on the leaderboard.[88]

Stimulate markets: Create and scale new markets

If building prototypes or launching pilots seeks new technologies, products, and services, market stimulation seeks their *commercialization*. Public organizations often want to develop products or services not yet available in the market, or want to broadly encourage markets to sell innovative products or services that can achieve a public good. Using prizes to simulate markets can be a powerfully and positively disruptive force. It can, for example, lead

to new cybersecurity capabilities, or foster the creation of next-generation sustainable energy technologies that governments and ordinary citizens can buy.

One example of a challenge that stimulated a market was the NASA/Google Green Flight Challenge, which sought to create emission-free flight vehicles, and led participants to invest more than $6,000,000 in pursuit of a purse of only $1,650,000. The Green Flight Challenge energized this nascent market; the two winning companies continue to make waves in the industry.[89] The first-place winner, Pipistrel, has developed additional ultralight aircraft models, with more than 350 of them flying around the world.[90]

Outcome benefits

- **Usher new ideas into the market**: Mechanisms such as advance market commitments and large purses can be effective incentives. For example, the Department of Energy's L-Prize is designed to develop a more efficient light bulb. The L-Prize is structured to provide the winner with an advance market commitment, a government promise to purchase a certain number of the bulbs at a guaranteed price, thus helping the market grow and become self-sustaining. Advance market commitments have also been used effectively to bring vaccines to populations that previously could not afford them.[91]

- **Redefine markets**: Prizes can spur private sector participants to commercialize technologies previously limited to government. For example, the now-classic Ansari XPRIZE created a rapidly growing market for private space vehicles, a domain previously dominated almost exclusively by government. They can also help to mature or refine existing markets. The Progressive Insurance Automotive XPRIZE sought to drive industry progress toward higher fuel efficiency standards. The challenge helped to demonstrate the commercial feasibility and desirability of automotive technologies that enable cars to go much further using less fuel.[92]

BY THE NUMBERS:
STIMULATE MARKETS[93]

- Total prize purse *(n = 4)*
  - Minimum: $1,650,000
  - **Median: $10,000,000**
  - Maximum: $15,000,000
- First place prize purse *(n = 4)*
  - Minimum: $6,000,000
  - **Median: $1,300,000**
  - Maximum: $10,000,000
- Start to submission length *(n = 4)*
  - Minimum: 87 days
  - **Median: 688 days**
  - Maximum: 840 days
- For marketing *(n = 4)*
  - 100% of prizes used partner outreach, press releases, and websites
- For targeted communications *(n = 4)*
  - 75% of prizes targeted engineers
  - 75% targeted industry professionals
- For motivators *(n=4)*
  - 100% of prizes used monetary incentives
  - 75% used commercial benefits
- Recognized winners *(n=4)*
  - Minimum: 2
  - **Median: 3**
  - Maximum: 6

THE PROGRESSIVE INSURANCE AUTOMOTIVE XPRIZE

Oil dependence and the impact of burning fossil fuels on climate change have long stirred concerns about the sustainability of US transportation infrastructure. The Progressive Insurance Automotive XPRIZE, supported by the Department of Energy, sought to address these issues by reshaping the automotive industry. The challenge incented companies to create a new generation of viable, energy-efficient vehicles. Designers attempted to transform the market by using the prize as an opportunity to create and popularize a new consumer metric called MPGe (miles per gallon gasoline equivalent), which offers consumers a way to compare new vehicles that use a variety of energy sources with conventional vehicles. Using this metric and a series of other clearly defined technical specifications that integrated notions of safety, affordability, and desirability, designers created a multiple-round challenge, which allowed a wide range of participants to embrace different kinds of technology, yet still be judged in a transparent and fair manner. Designers awarded $10,000,000 to the top three companies—all of their vehicles had over 100 MPGe—to ensure that the new market would have multiple players.[94]

- **Reduce the price of new technologies**: Due to high production costs, early innovations typically are out of reach for most consumers. Large-scale market adoption may not happen if production costs stay high. Prizes can help overcome this problem by creating incentives that target production costs or efficiency. The Department of Energy recently announced a prize focused on lowering the costs of energy produced by wave energy conversion devices.[95] Additionally, the Department of Energy, together with a coalition of over 200 major commercial building sector partners, developed the Wireless Meter Challenge. The effort engaged US manufacturers to build wireless sub-meters that cost less than $100 a piece, helping the government identify opportunities to save money by saving energy and giving coalition members the ability to buy lower-cost energy measurement tools.[96]

Critical design elements

Motivators—Make rewards large enough to sustain a business and stimulate the market

A large purse is required to support the high costs of market entry. Because market stimulation requires multiple participants to invest for an extended period (that is, the start to submission time is on average 604 days longer than challenges focusing on building prototypes or launching pilots), the purse should be structured to provide a substantial benefit for multiple winners. In fact, the size of the purse needed to stimulate a market can be over two orders of magnitude larger than those for challenges focused on building prototypes or launching pilots as an outcome.[97] By ensuring that multiple participants receive economic benefit and recognition as a part of the challenge, designers can encourage a larger, more diverse group to submit entries.

As noted previously, designers can incorporate commercial and networking benefits into their prize structures, such as inviting participants to trade conferences, promising advance market commitments and engaging end users and investors (such as venture capitalists) as judges. Doing so can expand participants' long-term stakes in the prize, encourage them to compete again, and attract others to the new space.

Evaluation—Balance technical performance with the ability to implement and scale

When evaluating prize submissions focused on market stimulation, it may be necessary to look beyond technical performance to a more qualitative, nuanced assessment of how a given solution might perform in a market setting. Thus evaluation criteria should include considerations of market entry, adoption, implementation, scaling, and firms available to

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exploit the opportunity over the long term. As an example, the Gates Foundation and USAID Haiti Mobile Money Initiative offered financial rewards for companies reaching certain transaction milestones in creating a market for mobile money services in Haiti.[98]

Structure—Sustain your efforts with post-prize momentum

To stimulate markets beyond the conclusion of the challenge, designers use post-award features such as communications, marketing, support, and incentives that can help participants continue to grow the market or scale solutions. Leading practices include promoting partnerships with key stakeholders interested in scaling solutions, hosting follow-up webinars, distributing regular email newsletters, and building mentorship programs. Mentorship can take many different forms, including pairing winners with more established players in the business community to help them build their networks.[99]

Recommended design tactics

- **Ensure regular touchpoints between designers and participants**: Regular interaction can help ensure participants continue to develop the market. Multiple rounds and milestone payments provide designers and judges with opportunities to ensure that participants maintain momentum in the newly formed marketplace.

- **Keep the customer involved**: When seeking solutions for a particular set of customers, designers should carefully consider their needs and requirements. One effective tactic is to create opportunities for participants to demonstrate their solutions to and receive feedback from the customers themselves. This provides critical user information and can identify key design flaws in the product or service before the challenge concludes. The Qualcomm Tricorder XPRIZE is using this practice. The challenge is focused on improving public health through a futuristic solution—a palm-sized wireless device that can monitor and diagnose health conditions. The designers are planning consumer tests and have engaged in a partnership with the FDA for regulatory reviews.[100]

- **Establish advisory boards**: Leverage diverse industry stakeholders and organizations that can:

  1. Provide input on prize design, administration, and legacy activities

  2. Help the prize sponsors navigate the changing regulatory and market landscape over the long period of time these challenges usually run

  3. Prepare key industry stakeholders for embracing the outcomes of the challenge if successful

Engaging people, organizations, and communities

Raise awareness: Enhance exposure and educate on an issue

For many public organizations, raising awareness of the public or key stakeholder groups is a central part of their mission. This can be part of a series of integrated goals or a primary objective, such as increasing public knowledge of a particular service, topic, or issue. Successful designers who wish to raise awareness typically choose design elements that engage large populations, involve robust marketing plans, and feature clear metrics for evaluating success.

To raise awareness using prizes, designers find it helpful to get specific about who is in their audience. For some challenges, such as the SunWise with Shade Poster Contest, the

BY THE NUMBERS:

RAISE AWARENESS[101]

Total prize purse *(n = 146)*
- Minimum: $0
- **Median: $955**
- Maximum: $1,650,000

· First place prize purse *(n = 121)*
- Minimum: $0
- **Median: $1,000**
- Maximum: $1,300,000

· Start to submission length *(n = 130)*
- Minimum: 2 days
- **Median: 57 days**
- Maximum: 616

· For motivators *(n=144)*
- The top incentive was recognition (used by 94% of the prizes) followed by monetary (48%)

· For selection criteria *(n = 142)*
- 80% of prizes used subjective criteria
- 4% used objective criteria
- 15% used a mix of the two

· For judging *(n = 144)*
- 69% used expert judging
- 6% of prizes used public voting
- 26% used both

audience was quite focused—children under the age of 13. Effective design requires highly targeted marketing and communications to reach an audience like this.[102] In other cases, however, the audience can be quite broad, such as for the Famine, War and Drought (FWD) Relief campaign sponsored by USAID, which generated awareness and donations for these types of crises.[103] Designers are typically careful not to view broad audiences as undifferentiated or consisting of like-minded individuals who all have similar interests and goals. Rather, the larger the audience, the more important it is for designers to undertake audience segmentation, a type of marketing analysis that breaks large audiences into pieces, each of which has a common set of characteristics that can be targeted through specific media channels and with tailored messaging.

Outcome benefits

- **Raise topic awareness**: Prizes focused on raising awareness as an outcome can put new topics on the public's radar and educate people about critical issues. Designers can use these prizes to target the general population or specific communities of interest.

- **Garner collateral for future campaigns**: Prizes that raise awareness are sometimes used to obtain marketing materials, such as videos, artwork, or stories, from target populations. Prizes focused on these outcomes may also recognize excellence in a specific field.

Critical design elements

Motivators—Use a big megaphone as a reward

Challenges for raising awareness often have small purses because recognition is the primary reward. Successful designers use recognition to motivate participants by clearly

STOP BULLYING VIDEO CHALLENGE

The Health Resources and Services Administration's (HRSA) Maternal and Child Health Bureau, located within the Department of Health and Human Services (HHS), launched the Stop Bullying Video Challenge to help prevent and end bullying in schools and communities nationwide.

They worked with the Federal Partners for Bullying Prevention, an organization comprised of 9 departments and 34 different offices, to tap into a diversity of experiences and take advantage of local outreach capabilities. They also made peer-to-peer communication an explicit goal of the challenge to build community and foster positive exchange. Finally, all videos became part of a larger tapestry of ideas and solutions for future campaigns to prevent and end bullying through the www.stopbullying.gov website.[104]

communicating the types of acknowledgment winners will receive. The Small Business Administration's (SBA's) Small Business Week Video Challenge helped educate the public about how its programs and services can help entrepreneurs and small business owners start, scale, and succeed. Participants, in turn, used the challenge as an opportunity to market their small businesses and highlight how they had leveraged useful SBA programs. While no purse was offered, participants were incented to enter the challenge by the possibility of being profiled by both SBA Administrator Karen Mills and the White House through a Google + Hangout session.[105]

Evaluation—Check whether the intended awareness is being achieved

Maintain a concerted focus on evaluating the demographics and characteristics of participants during the entire prize. While it's important to select a winner, it is equally valuable to ensure that the appropriate participants and stakeholders are engaged and energized following award. Designers should develop metrics specific to the prize to confirm that their communication, marketing, and outreach efforts are working.

Communications—Partner with others to maximize reach

Successful designers invest time and money in marketing to build a prize's profile. Often, this involves partnering with an organization whose network can promote the prize within a target community. Strategic marketing can further the positive perception and prestige of the prize, thereby enhancing the value of its award and the recognition winners receive.

Recommended design tactics

- **Publicize awards**: Treat recognition as a reward and make it a centerpiece of your prize. Create and cultivate networks that will generate winning solutions through public events, social media, press releases, and organization websites. Offer certificates or virtual "badges" for websites and social media.

- **Maintain regular communication**: Invest time and resources to continue communicating with key participants and stakeholder communities after the prize concludes. Consider developing a blog or a newsletter to maintain engagement.

- **Evaluate impacts**: During and after the prize, measure participant demographics and evaluate how submissions are being used. For example, one useful measure could be how many individuals not previously engaged in a particular topic area became involved as a result of the prize. Such metrics can be incorporated into participant evaluation. For example, video challenges can be evaluated through crowd-sourced voting or a page view count.

Mobilize action: Spark engagement and build skills

While raising awareness is essential for driving change, mobilizing action is a more ambitious outcome. This outcome achieves multiple goals: It helps participants interact in ways that improve submissions; generates enthusiasm and publicity for the prize; and builds community among diverse groups. As John Bracken from the Knight News Challenge put it, the human network that comes out of a challenge is the "currency we care most about."[107] Designers can use challenge mechanisms to encourage participation in capability building, networking events, mentorship activities, and workshops.

Just as designers identify audience segments when trying to raise awareness, they also carefully consider whom they are trying to mobilize, because different actors are compelled to behave in distinct ways. The "unit of mobilization" can vary dramatically, from individuals, teams, and groups to organizations, institutions, and subnational governments. Using different forms of analysis—consumer, market, regulatory, and organizational, to name a few—designers must evaluate the incentives and barriers to action for each of these actors to craft a prize that will mobilize them effectively. This analysis then informs the prize structure and, most importantly, its rules.

Action-oriented challenges are not necessarily trying to create collaboration among participants, unless it is useful for another outcome, such as developing a model or stimulating a market. In these cases, mobilizing action can look a little bit like private sector "coopetition," in which participants are simultaneously rivals and peer mentors.

Mobilizing action can be especially valuable for designers trying to build networks or communities of participants. A good illustration is the Department of Veteran's Affairs' Blue Button for all Americans providers contest, which sought to encourage of the use of Blue Button personal health records. The purse offered $50,000 to the first developer who coordinated the installation of Blue Button personal health records on the websites of 25,000 physicians and other clinical professionals.[108] RelayHealth won the challenge by making a Blue Button personal health record system available to all patients, including veterans, for more than 25,000 physicians across America.[109]

BY THE NUMBERS
MOBILIZE ACTION[106]

- Total prize purse *(n = 27)*
  - Minimum: $0
  - **Median: $30,000**
  - Maximum: $2,000,000
- First place prize purse *(n = 27)*
  - Minimum: $0
  - **Median: $3,000**
  - Maximum: $100,000
- Start to submission length *(n = 23)*
  - Minimum: 1 day
  - **Median: 66 days**
  - Maximum: 616 days
- For motivators *(n=27)*
  - The incentives were recognition (96% of prizes), monetary (67%), networking (44%), commercial benefits (37%), and capacity building (33%)
- 22% of prizes provide mentorship opportunities *(n = 27)*
- Top marketing strategies *(n = 27)*
  - Website (100%)
  - Press releases (96%)
  - Social media (74%)
  - Blogs (70%)

Outcome benefits

- **Connect communities**: Challenges that mobilize action bring together different groups of participants and can help them forge new identities associated with the challenge. For example, NASA's Zero Robotics Challenge, focused on student STEM engagement, requires individual teams to form alliances, fostering community building among the larger body of participants.[110]

- **Develop strategic partnerships and connections**: Action-oriented challenges can help designers create partnerships that can be used to advance their mission after prize implementation. Ashoka Changemakers accelerates lasting social change by bringing together high-potential social entrepreneurs through collaborative challenges.[111]

- **Enhance solution quality through collaboration**: Prize structures can yield higher-quality submissions by creating collaborative experiences that enhance participants' skills and abilities. For instance, if multiple rounds of the prize entail mentorship, feedback sessions, or even training, participants can use what they learn to improve their offerings in preparation for their final submission. Bloomberg Philanthropies' Mayors Challenge offers a particularly good example of this dynamic: 20 city finalists learn about innovative techniques and work together during Ideas Camp, while competing for the purse.[112]

- **Promote organizational change**: Action-oriented prizes also can be used by organizations seeking solutions from their own personnel. These prizes can help agencies find innovative ways to implement and scale solutions to organizational problems crafted by the people who understand them best. Prizes can spur participants to develop creative ways to roll out technological solutions across the organization, as illustrated by the Blue Button for All Americans providers contest.[113]

Critical design elements

Motivators—Amplify purses with recognition and networking benefits

Many prizes focused on mobilizing action and developing skills deemphasize the purse as the most important motivator. Instead, they find ways to highlight multiple participants in addition to winners, because recognition and network access also provide strong incentives to compete. For example, Facebook and the Gates Foundation hosted the HackEd 2.0 Hackathon, which assembled 24 teams of developers and educators to build educational applications addressing college readiness, social learning, and out-of-school learning.[114] The event showcased the developers' skills and gave them the opportunity to meet and interact with driven and passionate peers in an intense shared experience.

Structure—Help participants compete

Building adequate support structures for participants may require a larger operational budget. Funds can be allocated for workshops and conferences, mentorship resources during or after the challenge, and feedback sessions with partners who may also serve as judges. These interactions can provide powerful motivation, not only to get involved in the prize in the first place, but also to compete more intensely.

Communications—Start with a blitz and maintain communications post-award

To mobilize action and maximize impact across audiences, mount a branding, marketing, and media campaign focused on delivering the right messages to the right populations. Public organizations often lack the skills for this kind of strategic marketing and sometimes

NASA'S ZERO ROBOTICS CHALLENGE

NASA's Zero Robotic Challenge encourages high-school student STEM engagement. While the prize solicits algorithms to optimize the International Space Station's solar energy collection, it is primarily focused on developing acumen and excitement for STEM research.

It achieves this goal by working to create an enriching experience for student participants, so they can leverage their new skills and networks to excel in STEM courses. Students gain access to MIT resources throughout the challenge and cultivate a community by allowing the teams from various schools to interact through formal alliances. Finally, the winning team gets its algorithm deployed on the International Space Station.[115]

Through the use of these elements, designers have managed to make Zero Robotics an annual prize in both Europe and the United States. Several of the teams repeatedly participate—an indicator of the challenge's brand strength and the health of the communities it fosters.

even the culture to embrace it. Without it, however, designers risk creating a powerful prize for which no participants, or the wrong ones, show up. Post-award communications are also critical, because a central output of most prizes is building community. Nurturing and championing this community will keep participants focused on the original problem well after the prize is awarded. Failing to continue the conversation and channel their energy will compromise the prize's lasting impact.

Recommended design tactics

- **Encourage teams**: Forums that provide public leaderboards, coupled with communication features that encourage teams to collaborate and share information, increase the likelihood of more robust solutions. Kaggle, for example, allows individuals to meet through their forum and create new teams to continually test problem-solving approaches and solutions.[116]

- **Manage communities**: Limiting participant eligibility can increase the exclusivity of the prize and make the participants feel special for being involved. The EPA's Green Power Community Challenge, for instance, encourages communities to compete to achieve the highest green energy percentage of total electricity use. Eligibility for this prize, however, is limited to those the EPA has already designated as Green Power Communities.[117]

- **Promote your competitors**: Designers should consider marketing on behalf of participants. The Knight Foundation, for example, openly promotes finalists. By profiling finalists on its websites as well as blogging and tweeting about them, the foundation creates "a meaningful bump in credibility and attention [for] these applicants."[118] In addition to promoting finalists, designers also can highlight the larger participant community, demonstrating goodwill and building interest in the next challenge.

Inspire transformation: Organize for sustained change

As the craft of incentive prize design becomes more nuanced and sophisticated, so too do the outcomes to which designers aspire. Perhaps the boldest involves inspiring transformation. While some might argue that the distinction between mobilizing action and inspiring transformation is simply a matter of degree, designers who build transformation-oriented prizes more often have grand visions about how to address complex, seemingly intractable problems.

Few prizes seek this outcome. The Aspen Prize for Community College Excellence,

however, clearly illustrates how a refined design can generate fresh, powerful, and scalable ideas for reshaping community college education throughout the United States.[119] Bloomberg Philanthropies' Mayors Challenge, recently expanded to Europe, offers another excellent example, with an emerging, potentially global platform for driving municipal innovation and connecting innovative public officials.[120] Both challenges inspire transformation by targeting participants—community colleges and city leaders, respectively—that can take significant action and develop new models for change ready for adoption by others.

To inspire transformation, designers typically focus on a few, critical design elements, in a multiple-round process that helps to amplify the fundamental vision of the prize.

Outcome benefits

- **Mobilize scalable change**: Prizes focused on inspiring transformation seek to mobilize broad communities to engage in lasting change. Nesta's Big Green Challenge encouraged hundreds of groups to develop plans for reducing carbon dioxide emissions in their communities.[121] Once developed, these solutions will help other communities reduce their carbon footprint. Additionally, the Rebuild by Design competition provides an excellent example of mobilizing a community of leading engineering, architecture, and design firms, as well as highly regarded research institutions from around the world, to innovate on an important regional issue: the development of scalable, resilient design solutions for communities impacted by Hurricane Sandy.

- **Encourage collaboration to address large-scale problems**: Transformation cannot happen unless many different types of organizations work together. For instance, the Georgetown University Energy Prize encourages diverse communities and local governments to work together to reduce energy consumption.[123]

BY THE NUMBERS

INSPIRE TRANSFORMATION[122]

- Total prize purse *(n = 7)*
  - Minimum: $0
  - **Median: $0**
  - Maximum: $500,000
- First place prize purse *(n = 7)*
  - Minimum: $0
  - **Median: $0**
  - Maximum: $100,000
- Start to submission length *(n = 5)*
  - Minimum: 3 days
  - **Median: 60 days**
  - Maximum: 101 days
- 57% of prizes were recurring *(n = 7)*
- Average number of judging partner organizations *(n = 6)*
  - Federal: 0.43
  - Non-profit: 1.67
  - Private: 2.67
- Social media (74%)top marketing strategies *(n = 7)*
  - Website (100%)
  - Press releases (96%)
  - Social media (74%)

Critical design elements

Structure—Demonstrate performance through multiple rounds of competition

Successful designers use multiple competitive rounds to winnow the playing field. The Aspen Prize for Community College Excellence uses three rounds, employing

quantitative and qualitative assessments as well as a finalist selection committee to reduce the field of entrants to one winner and four finalists with distinction. Because this process helps the institute gather and analyze a remarkable amount of educational data about community college performance, it can select winners whose educational solutions are proven to make a difference.[124]

Communications—Publicize the underlying issue

Those seeking to transform communities rely on robust marketing and communication plans that target different participant populations as well as the public through appropriate media channels.

The Knight Neighborhood Challenge is a case in point. When the Community Foundation of Central Georgia first launched the Knight Neighborhood Challenge competitive grant program to revitalize the College Hill Corridor neighborhood in Macon, Georgia, it thought that the challenge itself would have enough brand recognition to attract a range of viable applications. After initial enthusiasm for the challenge faded, however, the foundation ran two marketing campaigns with a public relations firm to spread the word about the prize through social media. The challenge is now in its fifth year.[125]

Evaluation—Recruit the right judges

To inspire transformation, designers often ask for innovations whose performance may not be easily or quantifiably measurable. While this poses a challenge, selection of the right judges can help. Designers typically look for high-profile judges—public officials, authors, well-known scientists, and even celebrities. The star power of the judges' panel can help to establish the authority required to definitively select a winner. Famous judges also bring greater media attention to the prize, increasing its impact among participants as well as the public.

Recommended design tactics

- **Create a series of challenges**: Recurring prizes build brand recognition, attracting increasingly diverse groups of participants. Over time, they help to grow a community

ASPEN PRIZE FOR COMMUNITY COLLEGE EXCELLENCE

Community colleges provide most of the nation's continuing education and skills development. The Aspen Prize for Community College Excellence attempts to improve outcomes for community college students by identifying best practices and replicating them across the country.

To achieve this goal, Aspen's team worked with data experts to create clear metrics (for example, labor market and learning outcomes) that helped colleges prioritize certain objectives. By tapping the expertise of former community college experts as judges, Aspen added credibility to its measures. Aspen's competition involved three rounds: The first scoped eligibility, the second winnowed 120 candidates to 10 finalists, and the third chose a winner. This structure allowed Aspen to focus on collecting different kinds of qualitative and quantitative data at different stages, leading to a valuable dataset for future use. It also chose to make its prize recur every two years, extending stakeholder engagement and continuously promoting the new metrics. Aspen also invested heavily in communications, working with the major community college associations to broadcast to their networks, build credibility, and publish reports that aggregated best practices identified during evaluations of competing schools. In addition, Aspen focused on raising the profile of every participant. For example, it sent model press releases and helped colleges publish these in local newspapers to build participant profiles within their communities.

With these steps, Aspen was able to elevate the profile of community colleges, redefine excellence for them, and disseminate leading practices that can drive success across the education sector.[126]

of interest to drive change. The prizes themselves can become more sophisticated and targeted as the designers learn what works to achieve the best outcomes.

- **Obtain expert advice early**: Effective designers involve experts early in the design process to define problem statements for complex prizes and carefully develop metrics aligned with the transformation desired. The process often involves multiple stakeholders and may require a lengthy review period.

- **Provide post-award marketing for participants and the public**: A robust post-award communications plan increases participants' accountability, so they will continue to work on their ideas after the prize is awarded. Designers can use webinars and conferences to encourage collaboration and communication within the participant community. They can also take advantage of multichannel media communications to highlight successes to a broader audience.

Trends and insights

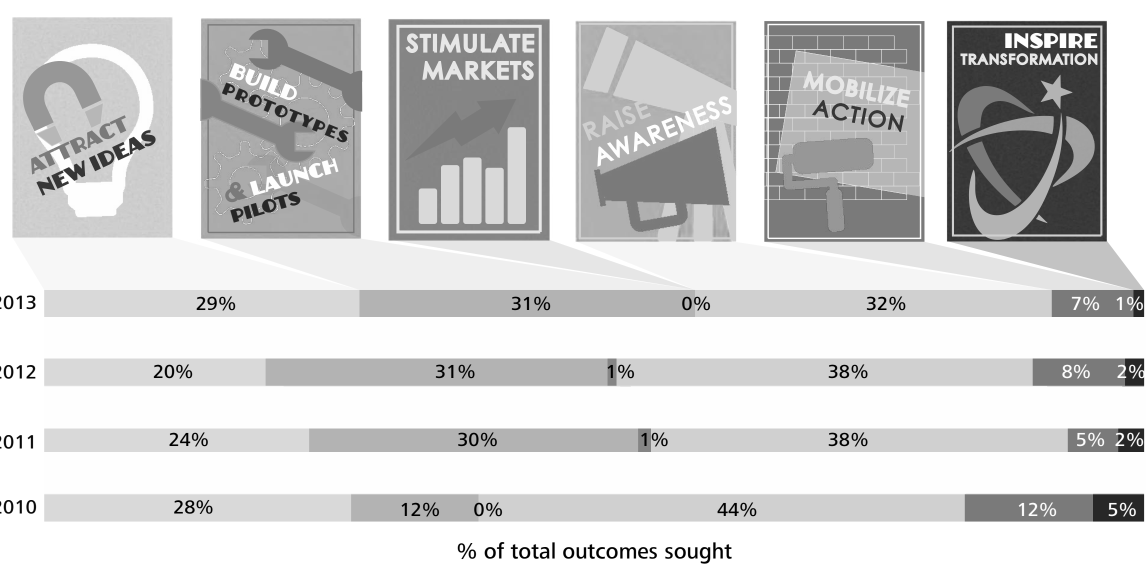
BASED on the analysis conducted for this report, three trends have emerged over the past five years that provide insight into how designers are building effective challenges and focusing their time, energy, and creativity to get the greatest return from their investments. All of this activity is helping prizes become a standard part of the challenge landscape and an important innovation tool that public sector leaders can use to pursue their missions. In the future, prizes will likely become commonplace and will be integrated even more tightly with challenges and other complementary problem solving strategies that public sector leaders use to drive change.

1. Challenges are becoming bolder and more sophisticated

Within the US government in particular, designers are increasingly expanding the scope, scale, and complexity of challenges and dedicating additional resources to fuel their ambitions.[127] These designers are using challenges to achieve multiple outcomes, experimenting with customized designs, and seeking to engage ever-larger audiences in public sector-focused innovation.

The growing popularity of complex challenges can be seen in the shifting mix of desired outcomes over time. While designers have never sought outcomes in equal

Figure 5. Prize outcomes over time as a percentage of total outcomes sought by designers (n = 43 (2010); n = 87 (2011); n = 119 (2012); n = 108 (2013))[128]



Graphic: Deloitte University Press | DUPress.com

proportion, there has clearly been growth in the pursuit of bolder outcomes that require more complex design. After America COMPETES Reauthorization Act passed in 2010, public sector challenges focused on raising awareness and attracting new ideas as outcomes dominated the landscape. More recently, designers have been increasingly trying their hand at producing models, such as prototypes and pilots.

While challenges are becoming more complex on the whole, the most ambitious outcomes on both spectra—market stimulation and inspire transformation—continue to make up a very small percentage of challenges on Challenge.gov, comprising less than 2 percent of outcomes sought in the last three years. Nonetheless, certain designers, including philanthropic, international, state, and local organizations, have been pursuing challenges that are larger in scope, targeting the more ambitious ends of the outcomes dimensions in greater percentages. As designers continue to experiment with increasing levels of complexity, there is an opportunity to capitalize on these more ambitious outcomes.

2. Challenge designers are partnering in new ways

Designers have focused on achieving these more complex outcomes by maturing their interactions with external organizations. In part, these collaborations help to reduce the risk of taking on challenges alone, because designers often need to supplement their own capabilities with outside partnerships. To obtain this kind of support, novice designers are moving beyond their organization's traditional partnerships and looking to experienced designers for support and guidance. Such experienced designers frequently come from organizations that have developed extensive design expertise though execution over the years and are willing to share both guidance and resources.

NASA, HHS, and USAID provide examples of how agencies are partnering in new ways to improve challenge design and administration.[129] US government agencies are collaborating with each other to share insights and best practices as well as increase the impact of their challenges.[130] For example, NASA has consistently brought its deep design expertise to its partners, such as in the LAUNCH challenge with USAID, Department of State, and NIKE Inc. Additionally, the My Air, My Health challenge, which is jointly administered by the HHS and the EPA, relies on each organization's particular expertise to incent solvers to develop sensors that track pollutant effects on individual health.[131] These agencies also worked with non-profits and private enterprises to capture key information critical to certain elements of the challenge. USAID's Technology Challenge for Atrocity Prevention included Humanity United in the task of problem definition and then worked with InnoCentive to translate their technical requirements into something a broader external audience could understand.[132] All of these efforts illustrate how cross-government and cross-industry collaboration can yield stronger challenge design and broader reach than challenges pursued by organizations alone.

As major advocates for the use of challenges in driving innovation and improved outcomes for social policy issues, philanthropic organizations will continue to play a major role in the public sector challenge design space. Because they are dedicating significant resources to challenges and are achieving successful outcomes, philanthropies have become one of the most important repositories of design knowledge. This expertise, coupled with philanthropies' politically unconstrained focus on the public good, puts them in a unique position to serve as engines of challenge design

innovation in the future.[133] New designers will continue to rely on these leading organizations for partnerships, guidance, and advice as they embark on building their first prizes and challenges.

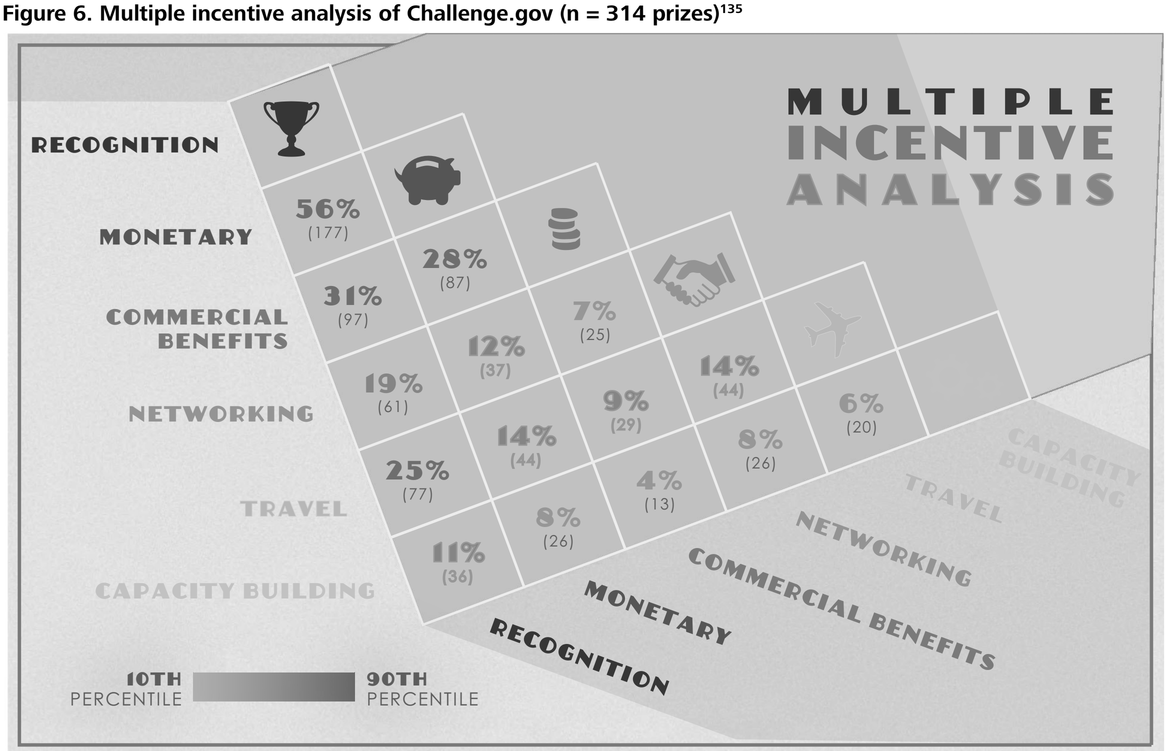
3. Challenge designers are expanding their view of incentives and challenge structures that can attract participants

In recent years, there has been significant experimentation with incentive structures to attract participants. While discussions with successful designers reveal that monetary and recognition incentives remain important, there is a movement to expand the universe of what organizations can offer to participants. Incentives such as an advanced market commitment, travel, commercial benefits, and capacity building are less frequently used, but can be just as powerful for attracting participants as monetary rewards.

Designers use multiple incentives to motivate participants. The Federal Virtual Challenge run by the US Army, which is focused on producing functioning prototypes of virtual environments while also mobilizing and supporting participant communities, provides a strong example of this trend. While the challenge includes a significant monetary purse (over $50,000), it also features other rewards, such as public recognition, travel to a demonstration conference, and networking and business opportunities among the virtual software community.[134] These non-traditional incentives illustrate how prize designers can creatively mix different types of motivations to attract the right participants.

While our Challenge.gov and supplemental data analysis shows that recognition

Figure 6. Multiple incentive analysis of Challenge.gov (n = 314 prizes)[135]



Graphic: Deloitte University Press | DUPress.com

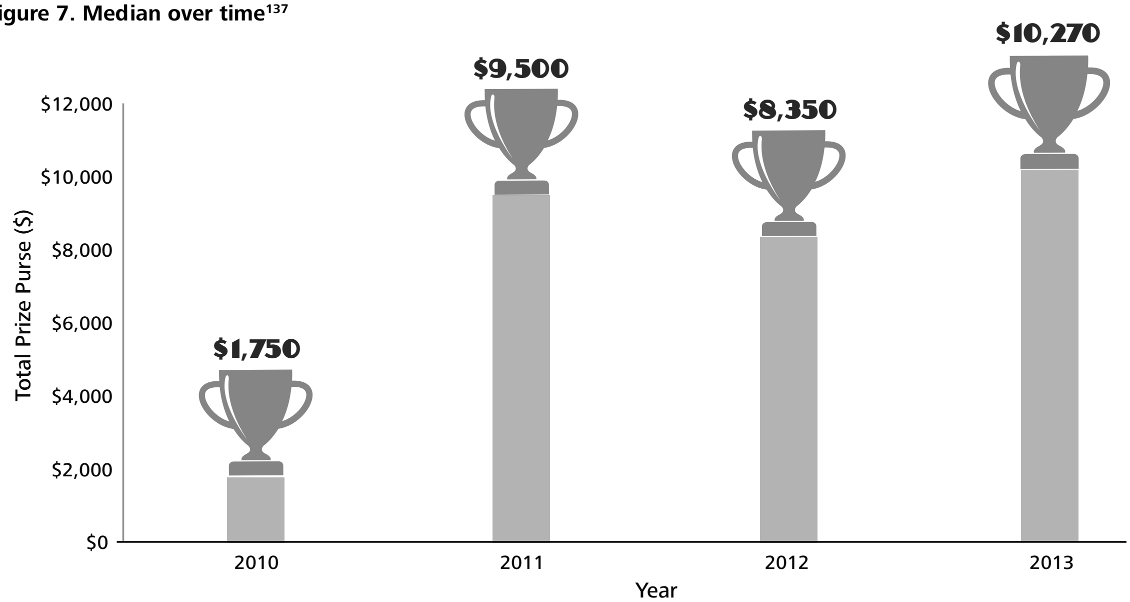
and monetary incentives were used in the majority of challenges, there were also many challenges that featured alternative motivations and combined multiple incentives to create a more effective draw (see figure 6).

While the use of monetary awards may not be the only incentive that designers use, there are some trends specifically related to this incentive that illuminate how designers approach their purse decisions. Over the past few years, there has been a jump in large purses. In 2010, there were only two federal challenges with a total purse over $100,000. In 2012 and 2013, this number increased to 13 and 9 challenges, respectively. This sustained growth, however, has not been as consistent for the median purse size.

There was a large median total prize purse increase from 2010 to 2011 (with a 543 percent increase from $1,750 to $9,500), but since then, the amount has hovered between $8,000 and $10,000. Our secondary dataset also suggests a similar plateauing effect (increasing from around $30,000 in 2010 and plateauing around $100,000 between 2011 and 2013). The disparity in purse size between the two datasets is likely due to the types of organizations (for example, philanthropies) in the second dataset (see appendix B for further details).

Over the coming years, this focus on blending incentives to achieve outcomes will likely continue. Many expert designers believe that the incentives focused on bringing together and building communities will provide strong draws for participants.[136] The convening of participants through the phases of a challenge can be transformative for both the participants and the designers themselves, as both groups ultimately learn a great deal about the ability of a challenge to effect change.

Figure 7. Median over time[137]



Graphic: Deloitte University Press | DUPress.com

STATE- AND LOCALLY FOCUSED CHALLENGES

Public sector leaders at the state and local levels are increasingly finding opportunities to compete in challenges as participants.[138] These challenges hold the promise of helping public sector leaders to advance their innovation agendas. Notable examples include the US Department of Education's Race to the Top Fund and Bloomberg Philanthropies' Mayors Challenge, which feature state and city government participants, respectively.

Challenges that engage government participants seek outcomes that range from hyper-local to broadly national:

- **Using challenges to create local solutions:** The CoolCalifornia City Challenge,[139] a partnership among the California Air Resources board, the University of California's Renewable and Appropriate Energy Laboratory, and the Energy Upgrade California™ Initiative, is a competition between cities to reduce their carbon footprint. California cities win sustainability funding if they successfully lower household energy use and transportation emissions through personal and team-focused initiatives and solutions.

- **Launching challenges to garner national attention:** The Talent Dividend Prize, sponsored by CEOs for Cities and the Kresge Foundation, will be awarded to the metropolitan area that exhibits the greatest increase in the number of post-secondary degrees granted per one thousand people over a four-year period. As part of the award, there will be a national promotional campaign featuring the winner to showcase the value of local talent development for other metropolitan areas. Currently, the prize has drawn participation from over 50 local governments.

As more governments participate in challenges, public sector leaders will need sound advice to determine when and how engage in these efforts. We offer below some general guidance based upon several high-profile examples, professional expertise, and inferences from our broader public sector challenge research.

1. **Find a senior leader to sponsor challenge participation**. While several challenges, such as Bloomberg Philanthropies' Mayors Challenge, target public sector leaders as their principal participants, most are not so specific. In these cases, government employees who wish to participate in a challenge will find that securing a senior government sponsor brings many advantages. From committing resources to managing stakeholders to communicating with the public, senior sponsors can help to create the conditions in which a state or local government can compete effectively. Through leadership and the power of convening, sponsors can also foster innovation and drive change. In fact, winning the challenge may not be the most urgent priority for sponsors who are willing to play this role. Challenge participation can focus government and citizens on innovative solutions that can still be pursued no matter who wins. Without the right sponsor, state and local challenge participants can have great difficulty translating their effort to compete into meaningful outcomes for their citizens.

2. **Engage constituents in solution development**. There are several reasons why government participants should seek opportunities to engage their constituents. Engagement drives citizens' awareness and buy-in that their tax dollars are being spent wisely to compete in a challenge that will bring tangible benefits. It helps to improve solution quality, as citizens can offer their governments ideas, expertise, and feedback about how best to develop the most powerful submissions. Finally, for some challenges, engagement is a formally evaluated requirement. Many challenge designers are now including community engagement and ease of implementation as part of their evaluation process. For example, the Georgetown University Energy Prize evaluates how participants demonstrate success in engaging their communities.[140] What better way to address such criteria than with a solution co-designed and/or approved by the very constituents who will be impacted?

3. **Plan for the work required to compete**. Because challenges designed for state and local government participants often seek bold outcomes, it can be difficult for participants to simply bootstrap their submissions with just a few resources. Rather, submission development can involve full-time staffs that will need to develop and launch new programs through intra-governmental collaboration and public-private partnerships. To understand what it will take to compete, participants should engage challenge designers to understand how the incentives and scoring are tied to desired outcomes. These conversations can lead to practical insights about how much time and effort will be required and how best to commit scarce resources. For recurring challenges, participants should also consider networking with winners from prior years to better appreciate the day-to-day requirements for competition. Ideas Camp, a key design feature of Bloomberg Philanthropies Mayors Challenge, provides participants with all of these opportunities, allowing them to interact with and learn from designers, competitors, and prior finalists over the course of a two-day workshop, well in advance of the final submission deadline.

4. **Include the office of the general counsel and the tax department**. Before registering for a challenge, it is critical to evaluate laws and regulations that may impact participation or winning. Challenge designers may not fully take into account how state and local laws impact participants' ability to receive or use a prize purse or non-monetary incentives. Consultation with the office of general counsel and the tax department can not only prevent unwelcome surprises, but can also help government participants evaluate how best to leverage the post-challenge period for achieving their innovation goals. For challenges that require public-private partnerships or teams, this consultation can be especially valuable.

5. **Focus on challenges that build capabilities**. As the number of government-focused challenges grows, state and local participants will want to selectively decide when to undertake the effort to compete. In certain cases, the challenge award and associated publicity may be sufficient incentives. In other cases, however, participants should consider whether their investment to compete will build lasting capabilities that benefit the government and its citizens. Many challenges now feature non-monetary rewards, such as mentorship and coaching, collaboration with peers, and networking or partnerships with industry, investors, and/or research institutions. For example, the Obama Administration's Strong Cities, Strong Communities (SC2) initiative focuses on assisting US towns, cities, and regions in advancing their economic agendas by enhancing the capabilities of local governments via technical assistance, access to federal agency expertise, and the formation of public and private sector partnerships.[141] By taking advantage of these opportunities, government participants can become better innovators and problem solvers.

Conclusion

In researching and writing this report, the Doblin team thought we had a straightforward goal: Evaluate the range of incentive prize activity over the past five years and distill it into practical advice that designers could apply to their own prizes. The volume and richness of the design activity that we discovered during this time period fundamentally challenged how we thought about prizes. With so much experimentation happening, it became hard to match prize types to actual prize activity, difficult to fit standard prize development processes to the range of actual designs, and challenging even to maintain a clear definition of challenges and prizes. In sum, incentive prize design for the public good turned out to be a brisk, messy business.

To make this complexity manageable for designers, we borrowed, synthesized, and organized the language and concepts used by the most able at this craft. We quickly learned that successful designers talked first about their goals and outcomes, which became their north star for building prizes. We also heard them describe the elemental activities in which they engaged to assemble prizes that achieved these outcomes. These are the core ideas featured in this report. Our contribution is to explain and illustrate them, show their connections and, if we were successful, make them practical and digestible for a broader audience of public, philanthropic, and private sector leaders and designers. More work is certainly needed to investigate the combinations of design elements that can increase the likelihood of success for the most ambitious outcomes: stimulating markets and inspiring transformation. Additional research and analysis are also necessary to better apply robust evaluative techniques and principles to incentive prizes and better measure their impact during and after prize implementation.

Incentive prizes are powerful tools of change. In the public sector, they're particularly valuable because they help leaders demonstrate how governments can successfully innovate and engage citizens. The risk takers who wish to use this problem-solving strategy for the first time and the designers who are already at work building prizes for their own organizations now have a wealth of detailed guidance from which they can draw.

Appendix A

Advanced prize design guidance

THIS appendix provides additional guidance on how to link outcomes with challenge design, including tactical considerations for each of the six outcomes. Designers are more frequently structuring prizes for multiple outcomes, which requires blending of design elements and recognizing the trade-offs between the elements and the outcomes themselves. The US Department of Labor's Equal Pay App Challenge is a good illustration of a multiple-outcome prize. It encouraged the development of a web application and seeks to raise awareness about differing levels of pay between men and women. This challenge offered an interesting mix of incentives: a grand prize of five scholarships, an immersive program for digital entrepreneurs, and three other recognition prizes—conversation with an eminent social enterprise leader, nonprofit adoption of the app, and an accelerator program to launch the app publicly. This mix of incentives drew app developers to the challenge but also raised public interest in this issue. The challenge is a part of a larger portfolio approach that the US government is pursuing to raise awareness about the pay gap through legislation, executive orders, and task forces.

Our Challenge.gov data analysis revealed a pattern of challenges that seek a combination of outcomes across the two dimensions discussed in this report—developing ideas, technologies, products, or services and engaging people, organizations, and communities. More specifically, designers often pair attracting new ideas with raising awareness and developing prototypes and pilots with mobilizing action. When designers create these pairings, they often focus on evaluation criteria and prize structure as the most important design elements.

Attract new ideas: Solicit concepts and techniques

Common pitfalls: Poorly structured problem statements, lack of planning, and solicitation of non-workable solutions are common pitfalls associated with the design of challenges focused on attracting new ideas. Designers should adopt the mentality that the solutions generated are the first step in a series of portfolio prizes and other tools for driving innovation that will advance in maturity and complexity toward stimulating markets.

Design element	Design strategic considerations	Tactical guidance
Resources	• Guard against the development of overly narrow problem statements. Use external expertise to design problem statements that will lead to broadly workable solutions.	• Create an advisory board of potential end users from the private sector, trade associations, philanthropies, academia, etc., and solicit input on how to design the challenge in order to generate desirable solutions. • Test the problem statement with the advisory board through targeted interviews and ideation sessions to generate a list of likely responses based upon variations of the problem statement.
Evaluation	• Structure format of participant submissions for ease of evaluation. Given the low barriers to entry for the submission of new ideas, work to ensure that the evaluation period is not so lengthy that it deteriorates the experience of the participants.	• Use word limits and structured response templates to guide participants toward desired solutions and simplify the evaluation process. For example, a challenge focused on generating slogans should be limited to 25 characters while a challenge for a technical proposal should include an example submission on the current industry benchmark.[142] • *Dual outcome guidance with raising awareness: Use public voting to engage a broader audience beyond the competitor community. This approach does involve a trade-off, because the final ideas may be of lower quality without vetting by better-informed judges.*[143]
Motivators	• Plan in advance for future rounds of the challenge, which will focus on outcomes of increasing complexity. Create excitement around the problem by guiding the formation of a vibrant community of participants.	• Incorporate mechanisms into design that encourage and reward participant interaction and collaboration. This can include leveraging a platform with dedicated collaboration space, using rules to mandate cross-fertilization at certain points in the challenge, and including evaluation criteria that reward the organic formation/combination of teams with similar solutions. • Create motivators for future rounds of the challenge to prevent participant fatigue. Consider the broader cost of the challenge to participants (that is, resources invested in the challenge prevent investment in other areas) and develop motivators that will benefit the broader goals of the participant pool. As an example, mentoring will benefit the broader capabilities of a participant in comparison to a minor increase in purse size.

Design element	Design strategic considerations	Tactical guidance
Structure	• Develop mechanisms prior to the launch of the challenge to support participants in revising ideas if initial submissions do not meet expectations.	• Hold working sessions with the advisory board to evaluate the diversity and maturity of solutions throughout the submission period. Use this information to provide guidance for other participants and restructure eligibility requirements (that is, participant expertise and/or experiences) for future rounds. • *Dual outcome guidance with raising awareness: Use a multi-round or mini-challenge approach to allow open engagement and exposure to the topic in early rounds and down-selecting the best ideas through the later and final rounds. This will allow designers to reach participants most likely to provide high-quality ideas while also expanding engagement across a broader community. For example, NASA's Zero Robotics Video Challenge uses open eligibility in its first round to capture ideas for a video that promotes the student robotics challenge. In later phases, these ideas are pitched and the winners receive $500 to turn their ideas into videos that help raise awareness for the larger robotics challenge.*[144]
Communications	• Focus on building a strong brand around the challenge from the outset. A strong brand will increase the size and diversity of the participant community and the value of recognition to winners.	• Determine the types of media valued by the target audience (that is, traditional press, social media, etc.) through interviews with potential participants. Use this information to target marketing efforts in order to build a brand around the challenge and create broad public awareness.

Additional examples

- National Institute of Health, "Challenge to Identify Audacious Goals in Vision Research and Blindness Rehabilitation," https://www.nei.nih.gov/challenge/additionalinfo.asp.
- European Commission, "The Job Challenge," http://ec.europa.eu/enterprise/policies/innovation/policy/social-innovation/competition/challenge_en.htm.
- City of New York, "Young Men's Initiative – My Voice Our City," http://www.nyc.gov/html/ymi/html/home/home.shtml.
- USAID, "FWD – Famine, War, Drought," http://action.usaid.gov/.

Build prototypes and launch pilots: Produce, test, and improve models

Common pitfalls: Relying on the purse—even a large one—as a sole means of motivating participants is a common pitfall of designers seeking to build prototypes or launch pilots. There should be significant emphasis on complementary motivators (for example, the recognition, networking opportunities, and investment counseling) that will encourage participants to put their own capital at risk. Designers should recognize that they will need to study their potential participants to understand their constraints, opportunities, and impact on outcomes. Designers should also consider customizing communications to particular participant communities.

Design element	Design strategic considerations	Tactical guidance
Resources	• Build an understanding of the landscape of potential challenge participants, in order to appropriately shape purse size and problem statements. • Develop detailed plans for the use of testing facilities early in the design process to fully understand the impact on the cost, length, and fairness of evaluating solutions.	• Conduct landscape analysis prior to completing detailed design. The analysis should consist of an economic and technical assessment: – Economic assessment: Identify and assess potential participants and their likely fixed and variable costs for developing a solution through interviews and financial modeling. Structure a sufficiently sized purse and additional incentives based upon the forecasted economics. If the challenge entails high fixed costs, the purse should be large enough to justify the investment required to build a prototype and reduce participant risks.[145] – Technical assessment: Identify state-of-the-art prototypes and pilots related to the problem statement. Interview the developers of these prototypes and pilots to determine the technical challenges in achieving the desired outcome. Refine the problem statement based upon the identified challenges to create realistic goals for the challenge.[146] • For challenges that require the physical testing and demonstration of prototypes, designers must consider the cost, logistics, and impact of testing facilities on design. Considerations include testing location, validation protocols, cost/length of test, safety, and acts of God.

Design element	Design strategic considerations	Tactical guidance
Evaluation	• Focus on identifying and rewarding both the best technical solution and the solution with the best commercialization prospects. They are not always the same and both are necessary for long-term success of the prize.	• Expand the impact of the challenge by including a requirement for the submission of a scaling plan for the prototype or pilot in addition to the technical design. The plan should identify the requirements for bringing the prototype or pilot to full-scale production. Use this tactic to identify the most viable long-term commercial solutions in addition to the best technical solutions. • *Dual outcome guidance with mobilizing action: It is critical to maintain rigorous, quantitative evaluation standards for these prototypes. Balance the inclusion of more qualitative criteria (for example, those rewarding teaming, which will be important for commercialization) to link the evaluation of submissions to the goal of mobilizing action.*
Motivators	• Vary motivators based upon the community of participants. Designers should ensure that they build an understanding of the potential participants and adjust motivators as necessary.	• Tailor the motivators to the target community of solvers. For example, networking with the venture capital community to provide funding to bring prototypes to market is ideal for start-ups and entrepreneurial participants. In contrast, academic participants are likely best motivated through grants, publicity, and conference networking opportunities. Designers should be prepared to provide additional motivators (beyond increasing the purse) throughout the registration process, if the community of participants is smaller than anticipated or varies significantly from their projected participants. The added motivators can drive additional excitement around the prize.

Design element	Design strategic considerations	Tactical guidance
Structure	• Structure the challenge around the technological maturity of the desired outcome. Less mature models will require additional challenge rounds and development time.	• Design the structure of the challenge based upon the maturity of the technology of the prototype or pilot, including research and development, small-scale proof-of-concept, or commercial prototype. Each stage of technological maturity requires different rules and evaluation criteria. For example, a research and development prototype will likely require an extended multi-stage challenge to mature the associated technology to the desired outcome. In contrast, a challenge focused on the development of a small-scale, proof-of-concept prototype as an outcome will likely consist of fewer phases but focus more heavily on meeting objective performance criteria at lower cost. • *Dual outcome guidance with mobilizing action: Multiple rounds or mini-challenges can encourage competitors to work with one another and lead to the development of better prototypes. Breaking the challenge into rounds can provide opportunities for judge feedback that can improve participants' skills. Build participant communities by inspiring both challenge (for example, leaderboards) and collaboration (for example, teaming). Striking the right balance is important so that participants continue to work together after the challenge concludes*.
Communications	• Develop a targeted and extended communication strategy that consists of multiple channels and outreach methods. Length of the communications strategy is longer than challenges focused on attracting ideas and must sustain excitement.	• Sequence communications to recruit potential participants, share information with participants, and keep the broader community engaged throughout the challenge. Due to the extended length of the challenge, leverage diverse channels to drive momentum and build engagement and anticipation throughout the challenge. Designers should also develop metrics early to assess the effectiveness of their communication strategy within their target participant community. If the communication strategy is not successful, designers can supplement it with personal appeals to specific participants identified during the landscape analysis.

Additional examples

- DTRA, "Identifying Organisms from a Stream of DNA Sequences," https://www.innocentive.com/ar/challenge/9933138.
- Department of Energy, "Apps for Energy," http://appsforenergy.challengepost.com/.
- Commerce, "Census Return Rate Challenge," https://www.kaggle.com/c/us-census-challenge.
- Department of Energy, "Solar Decathlon," http://www.solardecathlon.gov/.
- Department of Defense, "Federal Virtual Challenge," http://fvc.army.mil/.

Stimulate markets: Create and scale new markets

Common pitfalls: Designers working on challenges to stimulate markets should have a clear understanding of market gaps or failures, and what would motivate new or existing market actors to fill or overcome them. Without understanding how these markets work, designers risk incenting participants to engage in market behaviors that are unrealistic, unprofitable, and unscalable.

Design element	Design strategic considerations	Tactical guidance
Resources	• Engage a broad community of external experts through an advisory board to design a challenge focused on addressing specific challenges preventing market development or growth.	• Expand advisory board composition from that developed for challenges focused on attracting new ideas. Since challenges seeking to stimulate markets frequently address market failures, unrecognized market requirements, or transformational technologies, it is important to understand operational demands from producers, requirements from regulators, and global consumer requirements. These considerations should be included in problem statement design. Representation from each of these stakeholder groups is advised.
Evaluation	• Create mechanisms to avoid potential conflicts of interest between sponsors and participants and limit gaming of the rules and evaluation criteria from participants. • Engage the broader public in the design of the challenge to generate interest in the broader problem/challenge.	• Establish an independent evaluation board. This group of experts should be distinct from the advisory board and focus solely on vetting evaluation criteria for potential flaws and assessing submissions. The independence of the evaluation board from the advisory board and potential participants is critical so that unbiased feedback may be provided.[147] • Consider holding a public comment period on the draft rules and evaluation criteria to identify potential issues before the challenge begins. This approach may be used to create early excitement from potential participants and the broader public.

Design element	Design strategic considerations	Tactical guidance
Motivators	• Create motivators for the participants, judges, and experts due to the heavy cost and time investment for all.	• Similar to challenges focused on developing models as an outcome, a detailed understanding of participant cost structure is required in order to determine the appropriate size of the purse to defray the investment costs and risks for the participants. In contrast to the aforementioned challenges on this spectrum, the purse may need to be larger than simply the costs of the participants. The purse must also be large enough to attract broad public attention and create demand for the solutions. • Due to the complexity of challenges focused on this outcome, numerous industry experts are likely needed at different points in time during the challenge. In order to defray additional costs for this expertise, reward market experts by offering "no-cost or low-cost" sponsorship opportunities, exclusive access to participants, and public recognition at different points in the challenge process (for example, launch, judging, and award). • Structure the post-award phase of the challenge focused on scaling the winning solution. Use additional funding mechanisms and partnerships to motivate participants to continue to refine promising solutions and maintain broad participant interaction following award.
Structure	• Establish a structure that permits iterative feedback between designers and participants. Reward participants for successfully achieving technical and economic milestones to maintain interest and reduce risk.	• Use multiple rounds or stages to support the scaling of the product and actual market testing. Provide milestone payments or advanced market commitments for achieving specific technical proficiency or sales targets. Both the market testing and payments will keep participants engaged, celebrate successes, and demonstrate impact.[148]
Communications	• Hire expertise needed to drive a successful public relations campaign and create an appealing narrative around the challenge to gain public interest.	• Engage public relations experts to design marketing messaging and create a grand narrative around the challenge. Focus the narrative more broadly than the actual desired outcome to appeal to the general public and create demand and interest around the outcome. • Use stories about the participants to amplify sustained marketing communications. Video highlights of the first and second rounds or participant testimonials can provide opportunities to build the grand narrative of the challenge. Public tracking of progress through social media feeds or other mechanisms can sustain media interest after the excitement of the launch has concluded.

Additional examples

- XPRIZE, "Wendy Schmidt Oil Cleanup X Challenge," http://www.iprizecleanoceans.org/.
- Department of Energy, "Sunshot Prize – Race to the Rooftops," http://energy.gov/eere/sunshot/sunshot-prize-race-rooftops.

Raise awareness: Enhance exposure and educate on an issue

Common pitfalls: In a crowded media environment, designers seeking to use challenges to raise awareness about an issue face the difficulty of customizing their messages and getting them to the target audience. Often, these designers fall into the trap of merely targeting the broadest possible audience in the hope that their target audience will somehow catch on. It is critical for designers to appropriately segment the audience for their challenge and build campaigns specifically related to the media consumed by that audience. Additionally, designers ignore post-award communications at their own peril, as they may represent the greatest opportunity to achieve the desired increase in awareness.

Design element	Design strategic considerations	Tactical guidance
Resources	• Build communications and marketing capabilities into administration staff core capabilities.	• Prioritize efforts on identifying design and administration staff with expertise leading marketing campaigns, crafting targeted messaging, and community outreach and organization. In particular, identification of resources with experience evaluating the impact of messaging on the target audience is critical.
Evaluation	• Focus evaluation criteria on selecting participants that aid in increasing problem awareness rather those that a solely deliver the best or most-refined solution.	• Increase the number of winners to gain broad exposure and expand the incentives to participate. This can be accomplished without an increase in the purse by expanding the number of "recognized" winners in different categories. While not every winner will receive a monetary prize, this approach will help to engage more participants. • *Dual outcome guidance with attracting new ideas: Use public voting to engage a broader audience beyond the competitor community. This approach does involve a trade-off, because the final ideas may be of lower quality without vetting by better-informed judges.*[149]
Motivators	• Develop understanding of the non-economic incentives that drive the target audience participation.	• Build a profile of the target audience and compare the impact of formal marketing campaigns and a challenge on that audience. This analysis can include discussions with public relations firms, measurement of benefits to running campaigns, and comparisons of the differences in costs across marketing channels.

Design element	Design strategic considerations	Tactical guidance
Structure	• Pair challenge outcomes with an additional target outcome to maximize reach and impact.	• Structure the challenge to include additional outcomes or as part of a larger group of challenges. Break the problem into multiple topics, including those concerning further engagement with individuals, organizations, and communities.[150] • *Dual outcome guidance with attracting new ideas: Use a multi-round or mini-challenge approach to allow open engagement and exposure to the topic in early rounds and down-selecting the best ideas through the later and final rounds. This will allow designers to reach the competitors most likely to provide high-quality ideas while also expanding engagement across a broader community. For example, NASA's Zero Robotics Video Challenge uses open eligibility in its first round to capture ideas for a video that promotes the student robotics challenge. In later phases, these ideas are pitched and the winners receive $500 to turn their idea into videos that help raise awareness for the larger robotics challenge.*[151]
Communications	• Create a multi-channel marketing campaign to account for crowded media markets.	• Create a plan for publicizing the challenge and the results within the targeted audience to amplify understanding of the problem. This will involve communications through a number of platforms and across partner networks to account for the different methods in which the target audience accesses and internalizes information. Extend marketing beyond a designated website or targeted email communications to other forums including social media and print media campaigns. Designers must also account for regional and international differences in communications and media markets.

Additional examples

- NSF/AAAS "International Science & Engineering Visualization Challenge," http://www.nsf.gov/news/special_reports/scivis/challenge.jsp.
- USDA, "Fruit and Veggies Video Challenge," http://fruitsandveggies.challengepost.com/.
- City of New York, "Young Men's Initiative – My Voice Our City," http://www.nyc.gov/html/ymi/html/home/home.shtml.
- USAID, "FWD – Famine, War, Drought," http://action.usaid.gov/.

Mobilize action: Spark engagement and build skills

Common pitfalls: Designers should be careful not to believe that recruiting participants into a challenge is sufficient to mobilize action. Getting participants and larger audiences to act typically requires facilitating the formation of new communities. Designers also need the credibility to incent participants to act in new ways. For this, branding and clear messaging are critical.

Design element	Design strategic considerations	Tactical guidance
Resources	Capitalize on the energy of existing movements, initiatives, and partners to supplement challenge infrastructure.	• Leverage infrastructure from established communities with a focus aligned with the target outcome, such as conferences and community initiatives. Designers can reduce cost and improve their understanding of target participants by engaging with leaders of initiatives that complement the problem. • Select and engage partners that can increase the level and depth of interaction with the communities of participants before, during, and after the challenge. Specifically, identifying and engaging partners with prior success in mobilizing action in communities similar to the target participants is advantageous.
Evaluation	• Create definitive measures of progress to determine success of the challenge and provide opportunities to revise and improve future challenges.	• Develop metrics that record progress for each phase of the prize challenge. Metrics must extend beyond participant counts and include ways of measuring the sustainability of relationships or the number of new entrants. Metrics will vary by challenge but core items should include new entrants within target communities of interest and include an assessment of activity/action following the completion of the challenge. • *Dual outcome guidance with building prototypes or launching pilots: It is critical to maintain rigorous, objective evaluation standards for submitted solutions. Balance the inclusion of more subjective criteria (for example, those rewarding teaming which will be important for commercialization) to link the evaluation of challenge submissions to the goal of mobilizing action.*
Motivators	• Incorporate a high degree of competitor collaboration while recognizing the trade-off between encouraging teams and maintaining challenge.[152] • Incorporate incentives that will build the skills of participants (for example, expert coaching, speaking opportunities, etc.).	• Use existing challenge participants to recruit new ones during the signup period. Embed recruitment of new participants in the scoring system. Trust that competitors will assist in developing and extended community that will last well after the challenge. • Engage independent coaches to serve as a team resource during participant progression throughout the course of the challenge. Assist participants in developing skillsets to mobilize others that are tangentially connected to the challenge after the challenge has completed. Many prize designers use judges to provide the same coaching opportunities, but making coaches separate from the evaluation process may provide added benefits, such as allowing participants to be more candid because they know they are not being judged.

Design element	Design strategic considerations	Tactical guidance
Structure	• Structure forums for meaningful personal interaction. Mobilizing action requires trust and commitment that may be best suited for direct contact. Structure forums for meaningful personal interaction. Mobilizing action requires trust and commitment that may be best suited for direct contact.	• Identify a set of possible locations for participants to interact. In-person conferences or meetings can create networking opportunities that also provide incentives for participants to enter the challenge. For example, the US Army's Federal Virtual Challenge showcased the competitors at an in-person conference where the winners were not only crowned, but also able to network with other colleagues in their field.[153] • *Dual outcome guidance with building prototypes or launching pilots: Multiple rounds or mini-challenges can encourage competitors to work with one another and lead to the development of better prototypes. Breaking the challenge into rounds can provide opportunities for judge feedback that can improve competitors' skills. Build competitor communities by inspiring both challenge (for example, leaderboards) and collaboration (for example, teaming). Striking the right balance is important so that competitors continue to work together after the challenge concludes.*
Communications	• Create an environment to generate a dialogue between participants and the broader community.	• Develop communications that elicit responses from participants to encourage dialogue around a problem. Unlike challenges focused on ideas, products, or services as an outcome, mobilizing action requires communication between designers, participants, and the public to advance the discussion on the target issue rather than simply relaying information to participants and announcing the winners to the public. For example, designers can send out a weekly question through social media that allows participants to broadcast their progress or provide thoughts and feedback to administrators.

Additional examples

- EPA, "ENERGY STAR National Building Competition," http://www.energystar.gov/buildings/sites/default/uploads/tools/2011_NBC_Report.pdf?149d-5071.
- NASA, "Balloonsat High Altitude Flight Student Competition," http://www.nasa.gov/home/hqnews/2010/jan/HQ_10-018_Balloonsat.html.
- Department of Energy, "Solar Decathlon," http://www.solardecathlon.gov/.
- Department of Defense, "Federal Virtual Challenge," http://fvc.army.mil/.

Inspire transformation: Organize for sustained change

Common pitfalls: Inspiring transformation requires scaling and institutionalizing behavioral change. This can often be achieved through centralized coordination and a top-down approach. On the other hand, transformation can also be achieved through decentralized or grassroots action. Effective designers are aware of both means, do not conflate them, and are intentional about which elements they use to evoke change.

Design element	Design strategic considerations	Tactical guidance
Resources	• Select partners with significant public recognition and the ability to capture attention on a broad scale.	• Engage partners with strong brands to raise the challenge's profile and reach a larger audience. Select partners with missions or heavy investment/perspective on the desired transformation. Leverage these partners to engage the targeted participants through their existing networks. Use the combined reach of your partners to create interest at the regional level, national level, etc., by highlighting that the problem is significant enough to bring together a group of preeminent partners.
Evaluation	• Develop meaningful measures to act as the new basis for discussion and progress around the problem.	• Use the challenge as an opportunity to refine and define metrics for the entire community and issue area. These metrics can set expectations and encourage sustained behavior change. The challenge can act as the forum for setting a de facto standard on how the issue should be monitored and addressed going forward. • Develop measures of success to help communities understand the scope and impact of the challenge. This context can provide a starting point for future marketing and participant interactions throughout the course of the challenge.[154]
Motivators	• Engage neutrally viewed surrogates or spokespeople to promote the challenge. Look to reduce potentially divisive politics around the problem being addressed and focus on transforming behavior.	• Use surrogates and other community leaders to promote the brand of the challenge, broadcast desired outcomes, and motivate participants. Communications from these individuals may be viewed more impartially than messages communicated in an official capacity from the administrators. Also, the use of surrogates or community leaders as the face of the challenge may reduce the politics or emotions surrounding the problem and enable the engagement of a broader audience.

Design element	Design strategic considerations	Tactical guidance
Structure	• Develop a reoccurring challenge to maximize impact by continuing broad dialogue around the transformation outcome and through progressively more competitive evaluation criteria.	• Due to the complexity of transformative outcomes, a recurring challenge can allow competitors to continue momentum and understand how their work is moving the field forward. For longer challenges, the design should be restructured to prevent community burnout and sponsor fatigue.[155] • After the first challenge, evaluate which aspects of the challenge to maintain for future challenges and determine potential areas for revision. Change the evaluation criteria to keep it interesting and perhaps more competitive. Test these potential changes with the past participants to understand if new approaches will energize and resonate with those competing.
Communications	• Plan on a sustained marketing effort that includes traditional and non-traditional marketing tactics.	• Determine the community you want to reach and the behaviors you want to change. The marketing effort should revolve around this community for a sustained period of time. In order to prevent messaging fatigue with the target community, identify potential viral or guerilla marketing tactics to vary the delivery and impact of the messaging.

Additional examples

- Bloomberg Philanthropies, “Mayors Challenge,” http://mayorschallenge.bloomberg.org/index.cfm?objectid=7E9F3B30-1A4F-11E3-8975000C29C7CA2F.
- EPA, “Gameday Challenge,” http://gamedaychallenge.org/.

Appendix B

Data analysis methodology

THE amount of available data on challenges has increased exponentially and tracks with the increase in the overall number of challenges. Even with this flood of data, the publically available information on challenges is inconsistent in terms of quality, difficult to categorize given varying challenge terminology, incomplete for all design elements, and not easily accessible from one centralized location. Because of these limitations, there are few data-driven studies that connect the strategic choices of challenge design with the outcomes sought by designers. This report tries to fill that gap with a deeper data analysis that incorporates new challenges from recent years, decomposes challenges into their design elements, and links this data to desired outcomes. Given the imperfect nature of the data, the primary goal of this analysis is to provide a rough starting point for designers, as they consider how to design their own challenges.

The following sections explain the data source selection approach, data collection process, analysis method, limitations, and opportunities for further research.

Data source selection

There is a wide range of public sector challenge data sources available to researchers. This report draws on two major sources: 1) challenges listed on Challenge.gov, and 2) challenges found on a select set of philanthropic, state, local, and international organizations' websites. This second dataset serves primarily as a way to validate the patterns of the Challenge.gov dataset and to identify the extent to which challenge insights relevant to these challenges may also be applicable to the larger challenge community. The second dataset includes challenges involving philanthropies and non-profits. These organizations were selected because they are established design experts, but this data collection method also captured some state and local organizations, as they frequently served as partners, competed as participants, or served as hosts. For example, the Talent Dividend focuses on improving educational outcomes in US cities and represents collaboration between the Kresge Foundation, CEOs for Cities, and over 57 local governments.[156] In addition to these two datasets, the authors used primary interviews and challenge summary reports from the White House Office of Science and Technology Policy (OSTP) to validate data points.[157] The final dataset includes 314 challenges collected from Challenge.gov and 89 challenges collected from the secondary dataset.

Data collection

Data collection involved three steps: 1) cataloguing all challenges found on the Challenge.gov and non-federal government websites; 2) identifying prize design elements and other data points for analysis, including: challenge title, type of organization, sub organization (if applicable), type and number of partners, challenge description, platform used, selection criteria (subjective, objective, hybrid), selection process (expert judging, public voting, hybrid), total prize purse, 1st place prize amount, prize awarded (Y, N), number of 1st place winners, number of recognized winners, prize start date, prize end date, submission date, multiple submission dates (Y, N), number of submissions, outcome, targeted audience, collaboration

allowed, mentorship provided (Y, N), segmentation elements (multi-round, multi-voting, etc.), other structural elements (leaderboard, reoccurrence, etc.), limited eligibility (Y, N), incentive type, and marketing approaches; and 3) validating data with information from primary interviews and White House OSTP challenge implementation reports.

Data analysis

Data preparation and organization for analysis included several steps: 1) conducting aggregate and time series analysis of specific data elements (for example, prize purse, prize length, etc.) for both the Challenge.gov and the secondary dataset; 2) conducting secondary aggregate analysis for each of the six outcomes identified in this report using the various data elements; 3) comparing analyses of both datasets to identify discrepancies and confirm cross-dataset trends; and 4) summarizing results in charts, graphics, and tables in the body of the report.

Limitations

The volume of challenge data represents a challenge for researchers. They can choose from a diverse set of data sources from different sectors and organizations. Even after identifying the right data source, researchers face issues with ensuring consistency in data quality and devoting enough time to collect information from the dispersed data spread across different sources. Additional challenges include the fact that data on design elements are not easily accessible and that different terms are used to reference similar challenges (for example, inducement prize, challenge prize, grand challenges)

Given these limitations, Challenge.gov was used as the primary data source because this website provides the most centralized location of public sector challenges available to researchers.[158] Recognizing the larger universe of challenges outside of those associated with the US government, the research team gathered the secondary dataset to provide a rough check on the trends and insights identified from this first source. From this data analysis, our goal was to provide descriptive statistics and trend analysis and was not intended to provide a more robust statistical analysis. The primary intention of this analysis is to demonstrate a new approach to categorize challenge-related data by highlighting emerging patterns and trends that emerge when design elements are analyzed by desired outcomes.

Future research

There are opportunities to expand on this data analysis and conduct studies that are more specific or larger in scope. One area of interest for future study is the quantification of return on investment for these different prizes. Additional research could expand the number and breadth of challenges included in this type of analysis to validate that Challenge.gov is an effective representation of the larger body of public sector challenges. Finally, local and state organizations, which are increasingly experimenting with their own challenges and participating in challenges run by others, could present another interesting area for study as more data becomes available.

Appendix C

List of interviews

DOBLIN conducted 27 interviews with 25 organizations and 45 individuals between February 5, 2014 and April 29, 2014. The following sections explain the data source selection approach, data collection process, analysis method, limitations, and opportunities for further research.

Name	Title	Organization
James Anderson	Lead for Government Innovation Programs	Bloomberg Philanthropies
Beverly Blake	Program director	Knight Foundation
John Bracken	Director, Journalism and Media Innovation	Knight Foundation
Erich Broksas	Senior vice president, Strategy & International Investment	Case Foundation
John Clarke	Government Innovation Programs	Bloomberg Philanthropies
Jason Crusan	Director of the NASA Center of Excellence for Collaborative Innovation	National Aeronautics and Space Agency
Alok Das	Senior scientist for Design Innovation	Air Force Research Laboratory
Jeff Davis	Deputy Director of the NASA Center of Excellence for Collaborative Innovation	National Aeronautics and Space Agency
Kathryn Dennis	President	Community Foundation of Central Georgia
Cristin Dorgelo	Assistant director, Grand Challenges	White House Office of Science Technology and Policy
Greg Downing	Executive director for Innovation	Department of Health and Human Services
Jonathan Greenblatt	Special assistant to the president and director of the Office of Social Innovation and Civic Participation	White House Domestic Policy Council
Jenn Gustetic	Prizes and Challenges program executive	NASA

Name	Title	Organization
Joseph Heaps	Deputy chief, Information and Sensors Technology Division	National Institute of Justice, Department of Justice
Steven Hodas	Executive director	Innovate NYC Schools
Kippy Joseph	Associate director, Innovation	Rockefeller Foundation
Tom Kalil	Deputy director for Technology and Innovation	White House Office of Science Technology and Policy
Maurice Kent	Agency lead, Prizes	United States Agency for International Development
Elizabeth Kittrie	Senior policy analyst	Department of Health and Human Services
Sarah Koch	Director, Social Innovation	Case Foundation
Kevin Kuhn	Innovation Team, Office of Research and Development	Environmental Protection Agency
Karim Lakhani	Associate professor of Business Administration	Harvard Business School
Bob Lee	Open Innovation project manager	Wright Brothers Institute
Xavier Le-Mounier	Directorate General for Enterprise and Industry	European Commission
Katie Leonberger	Government Innovation Program	Bloomberg Philanthropies
Tammi Marcoullier	Program manager, Challenge & Prize Competitions	General Services Administration
Nancy Merritt	Senior policy advisor	National Institute of Justice, Department of Justice
Bill Moses	Managing director, Education Program	Kresge Foundation
Clare Newman	Government Innovation Programs	Bloomberg Philanthropies
Anil Rathi	CEO and founder	Skild
Euan Robertson	First deputy commissioner	New York City Department of Small Business Services
Brian Sasscer	SVP, Strategic Operations	Case Foundation
Denice Shaw	Project lead, Office of Research and Development	Environmental Protection Agency
Ariel Simon	Chief strategy officer and deputy to the president	Kresge Foundation

Name	Title	Organization
Gretchen Crosby Sims	Vice president, Programs	Joyce Foundation
Michael Smith	Director, Social Innovation Fund, Corporation for National & Community Service	Corporation of National and Community Services
Michael Timmons	Director of Marketing & Client Services	Skild
Katheryn Viguerie	Office of Engagement and Communication, US Global Development Lab	United States Agency for International Development
Adam Wong	Management and program analyst	Office of the National Coordinator, Department of Health and Human Services
Julia Wood	Director of Donor Services	Community Foundation of Central Georgia
Josh Wyner	Executive director of the Aspen Institute College Excellence Program	Aspen Institute
Emily Yu	VP, Marketing & Partnership	Case Foundation
Marco Zappalorto	Program manager, Center for Challenge Prizes	Nesta

Appendix D
Technology platform vendors

THIS appendix lists a selection of prize technology platform vendors commonly found in our research.

Company name	Target audience	Example challenge	Website
ChallengePost	General	Apps for Healthy Kids	http://challengepost.com/
Health 2.0	Health care technologists	EPA/HHS: My Air, My Health Challenge	http://www.health2con.com/
InnoCentive	Scientists (physical, biological, chemical, etc.)	Department of State: Innovation in Arms Control	https://www.innocentive.com/
Kaggle	Data scientists	US Census Return Rate Challenge	http://www.kaggle.com/
OpenIDEO	General	Knight's News Challenge	http://www.openideo.com/
Skild	General	NSF International Science & Engineering Visualization Challenge	http://www.skild.com/
Tongle	Video makers	NASA Zero Robotics Video Challenge[159]	http://tongal.com/b/home
TopCoder	Computer scientists, programmers, developers	NASA International Space Station Challenge Series	http://www.topcoder.com/

For US government designers, additional information on vendors can be found in General Services Administration (GSA) Schedule 541 4G, Challenges and Competition Services.

Appendix E

Acronyms

Acronym	Meaning
AAAS	American Association for the Advancement of Science
AMC	Advanced Market Commitments
America COMPETES Act	The America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act
CMS	Center for Medicare and Medicaid Services
CoECI	Center of Excellence for Collaborative Innovation
DARPA	Defense Advanced Research Projects Agency
DoE	Department of Energy
DTRA	Defense Threat Reduction Agency
EPA	Environmental Protection Agency
FWD	Famine, War, Drought
GAO	Government Accountability Office
HADR	Humanitarian Assistance and Disaster Relief
HHS	Health and Human Services
MIT	Massachusetts Institute of Technology

Acronym	Meaning
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
OMB	Office of Management and Budget
OSTP	White House Office of Science and Technology Policy
SBA	Small Business Administration
STEM	Science, Technology, Education, Mathematics
SC2	Strong Cities, Strong Communities
UN	United Nations
USAID	United States Agency of International Development
USDA	United States Department of Agriculture

Endnotes

1. CBS News, "Red Cross: 3M Haitians affected by quake," http://www.cbsnews.com/news/red-cross-3m-haitians-affected-by-quake/, accessed January 13, 2010.

2. US Agency for International Development, "Haiti Mobile Money Initiative," http://www.usaid.gov/news-information/fact-sheets/haiti-mobile-money-initiative, accessed April 29, 2014.

3. Office of Science and Technology Policy, "Implementation of federal prize authority: Fiscal year 2013 progress report," May 2014, http://www.whitehouse.gov/sites/default/files/microsites/ostp/competes_prizesreport_fy13_final.pdf, accessed May 8, 2014.

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To: Erath, Amanda[aerath@usbr.gov]
From: Goklany, Indur
Sent: 2017-06-21T10:20:38-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-21T10:21:08-04:00

Hello Amanda -- I was wondering how we were proceeding on this? -- Goks

On Thu, May 25, 2017 at 11:20 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Amanda,
Attached are my comments/edits to Chapter 3.9 of the main report and suggestions for the uncertainty discussion in the Summary Report.

I also received a copy of the Niobrara Report (only the Summary and appendices). But my suggestion is let's do one at a time. Once we have wrestled with the Klamath report, it should be easier to address that.

Thanks, and best regards.

Goks

On Thu, May 18, 2017 at 5:05 PM, Erath, Amanda <aerath@usbr.gov> wrote:

Hello Goks,
Below is the uncertainty language that we have drafted to be added to the Klamath River Basin Study Summary Report. I have also attached the Klamath River Basin Study Full Report. Sorry for the oversight in not sending the Full Report to you. The Full Report includes uncertainty discussions near the end of chapters 3, 4, 5, and 6 (identified in the table of contents for each chapter). [redacted] (b)(5) Please let me know if you have any questions.

[redacted] (b)(5)

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On Fri, May 12, 2017 at 8:55 AM, David Raff <draff@usbr.gov> wrote:

Thanks. We'll read as well and incorporate into our uncertainty language as appropriate.

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:

[redacted]

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted]

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
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17-01174_013117;17-01174_013117;17-01174_013118;17-01174_013119

To: Erath, Amanda[aerath@usbr.gov]
From: Goklany, Indur
Sent: 2017-06-22T09:49:19-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-22T09:49:53-04:00

Hello Amanda-- I am trying figure out my schedule for the summer and would like to be able work it around work priorities such as the Klamath. Could you give me an idea as to when I can expect the next draft of this material? Thanks -- Goks

On Wed, Jun 21, 2017 at 10:20 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

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[redacted]

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Good Afternoon Again Goks,

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Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

Cc: Dean Marrone[dmarrone@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Amanda Erath[aerath@usbr.gov]
To: Indur Goklany[indur_goklany@ios.doi.gov]
From: David Raff
Sent: 2017-06-22T10:33:27-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-22T10:33:54-04:00

Good Morning Goks,

Thank you for your continued interest and attention to Reclamation's Basin Studies. We certainly appreciate the priority you are giving to the Klamath study.

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Date: Thu, Jun 22, 2017 at 7:49 AM
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To: "Erath, Amanda" <aerath@usbr.gov>

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> s [redacted] (b)(5) Please let me know if you have any questions.
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> ***Amanda Erath***
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17-01174_013123;17-01174_013123;17-01174_013124;17-01174_013125;17-01174_013126

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-06-22T12:41:40-04:00
Importance: Normal
Subject: Fwd: Climate discussion
Received: 2017-06-22T12:43:02-04:00

Hello Ryan,
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17-01174_013127;17-01174_013127;17-01174_013128;17-01174_013129;17-01174_013130

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17-01174_013131;17-01174_013131;17-01174_013132;17-01174_013133;17-01174_013134

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Nichols, Ryan
Sent: 2017-06-22T14:56:47-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-22T17:44:42-04:00

Do you have time this afternoon? I'm here until 6 pm.

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Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-06-22T15:00:07-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-22T15:01:34-04:00

I am here till 4:30 normally, but am free tomorrow.

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The attached sheet has the citations I was refering to regarding the modeled

rate of warming vs. observed rates. Some people refer to this , unfortunately, as a hiatus. I think that is more of a red herring. The correct terminology should be slowdown, possible followed by a question mark

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,
Wondering if this 2015 paper or an earlier version referenced here is the document you were referring to relating climate model performance:

http://www.meteo.psu.edu/holocene/public_html/Mann/articles/articles/grl53276.pdf

The performance seems pretty darn good overall especially when the point for us at a regional level is to describe the risk possibilities and not to pin point any specific projection. And particularly if there is a bias it is systematic and can be removed through a correction as Reclamation does.

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Advisor
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Department of the Interior

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-06-22T15:00:57-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-22T16:49:07-04:00

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Where would you like to meet?

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Amanda Erath
Program Analyst
Policy and Administration
Denver Federal Center
Building 67 (84-51000)
P.O. Box 25007
Denver, CO 80225-0007

Office: (303) 445-2766
Email: aerath@usbr.gov

On Fri, May 12, 2017 at 8:55 AM, David Raff <draff@usbr.gov> wrote:

Thanks. We'll read as well and incorporate into our uncertainty language as appropriate.

17-01174_013143;17-01174_013143;17-01174_013144;17-01174_013145;17-01174_013146;17-01174_013147

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:

[redacted]

(b)(5)

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted]

(b)(5)

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

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Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science

Department of the Interior

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Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

17-01174_013148;17-01174_013148;17-01174_013149;17-01174_013150;17-01174_013151;17-01174_013152

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-06-22T15:11:04-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-22T21:18:45-04:00

I can come to your office. I could use a break from here.

On Thu, Jun 22, 2017 at 3:09 PM, Nichols, Ryan <ryan_nichols@ios.doi.gov> wrote:

Where would you like to meet?

On Thu, Jun 22, 2017 at 3:00 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

I should have added that I'm free now.

On Thu, Jun 22, 2017 at 2:56 PM, Nichols, Ryan <ryan_nichols@ios.doi.gov> wrote:

Do you have time this afternoon? I'm here until 6 pm.

On Thu, Jun 22, 2017 at 12:41 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Hello Ryan,
Is it possible to meet with you on the Klamath River Basin and other climate change studies being undertaken by Reclamation?

The following e-mail thread will provide some background. I was hoping to meet with Alan Mikkelsen but he's out of town and will be in only sporadically until after the 4th. So while I was pondering my next step on this, Doug Domenech suggested that I talk to you.

Are you available any time today or tomorrow?

Thanks.
Indur Goklany (AKA Goks)

---------- Forwarded message ----------
From: **David Raff** <draff@usbr.gov>
Date: Thu, Jun 22, 2017 at 10:33 AM
Subject: Re: Climate discussion
To: Indur Goklany <indur_goklany@ios.doi.gov>
Cc: Dean Marrone <dmarrone@usbr.gov>, Avra Morgan <aomorgan@usbr.gov>, Amanda Erath <aerath@usbr.gov>

Good Morning Goks,

Thank you for your continued interest and attention to Reclamation's Basin Studies. We certainly appreciate the priority you are giving to the Klamath study.

Our Acting Commissioner, Mr. Alan Mikkelsen, is engaged to help identify the path forward he would like to take to meet the needs and expectations of our cost share partners as well as the administration.

As soon as we receive additional guidance we will address your previous comments as appropriate and circle back with you. I do not have a firm timeframe to provide to you but certainly hope it will be in the next few weeks. Thank you again and hope you are enjoying the start to summer.

Best Regards,
Dave

---------- Forwarded message ----------
From: **Goklany, Indur** <indur_goklany@ios.doi.gov>
Date: Thu, Jun 22, 2017 at 7:49 AM
Subject: Re: Climate discussion
To: "Erath, Amanda" <aerath@usbr.gov>

Hello Amanda-- I am trying figure out my schedule for the summer and would like to be able work it around work priorities such as the Klamath. Could you give me an idea as to when I can expect the next draft of this material? Thanks -- Goks

On Wed, Jun 21, 2017 at 10:20 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Hello Amanda -- I was wondering how we were proceeding on this? -- Goks

On Thu, May 25, 2017 at 11:20 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Amanda,
Attached are my comments/edits to Chapter 3.9 of the main report and suggestions for the uncertainty discussion in the Summary Report.

I also received a copy of the Niobrara Report (only the Summary and appendices). But my suggestion is let's do one at a time. Once we have wrestled with the Klamath report, it should be easier to address that.

Thanks, and best regards.

Goks

On Thu, May 18, 2017 at 5:05 PM, Erath, Amanda <aerath@usbr.gov> wrote:

Hello Goks,
Below is the uncertainty language that we have drafted to be added to the Klamath River Basin Study Summary Report. I have also attached the Klamath River Basin Study Full Report. Sorry for the oversight in not sending the Full Report to you. The Full Report includes uncertainty discussions near the end of chapters 3, 4, 5, and 6 (identified in the table of contents for each chapter). [redacted] Please let me know if you have any questions.

[redacted]

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David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

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Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

--
Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

17-01174_013153;17-01174_013153;17-01174_013154;17-01174_013155

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-06-22T16:32:40-04:00
Importance: Normal
Subject: Fwd: Climate discussion
Received: 2017-06-22T16:40:03-04:00
Uncertainty discussion for Summary.docx
KRBS_Full_Report_Final.ig.docx

Attached is the material I sent to Amanda last month. Also, the uncertainty language as originally drafted by Amanda is in the following thread in **bold**.
---------- Forwarded message ----------
From: **Goklany, Indur** <indur_goklany@ios.doi.gov>
Date: Thu, May 25, 2017 at 11:20 AM
Subject: Re: Climate discussion
To: "Erath, Amanda" <aerath@usbr.gov>
Cc: David Raff <draff@usbr.gov>, Marketa Elsner <mmcguire@usbr.gov>, Avra Morgan <aomorgan@usbr.gov>, "Dahm, Katharine" <kdahm@usbr.gov>, Arlan Nickel <anickel@usbr.gov>

Amanda,
Attached are my comments/edits to Chapter 3.9 of the main report and suggestions for the uncertainty discussion in the Summary Report.

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[redacted] (b)(5)

[redacted]

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The information presented in this report was developed in conjunction with basin stakeholders and is intended to inform and assist stakeholders by identifying potential future scenarios for long term planning. The analyses provided in this report reflect the use of best available datasets and data development methodologies at the time of the study. In accordance with common practice, the impacts assessment methodology employed here is based on using a series of models with the outputs of one model serving as the input to the next model. Since there are uncertainties associated with each model step, and the inputs driving each model step are themselves uncertain, this can lead to a "cascade of uncertainty" (IPCC 2007, here), although there may be situations where one model's tendency to over- or under-estimate may be countered at least to some extent by another's tendency to err in the other direction. While this study has not developed an estimate of the cumulative uncertainties in the results based on this methodology, it is important to acknowledge the uncertainties inherent within projecting future planning conditions for water supply and demand. For example, projections of future climate, population, water demand, and land use contain uncertainties that vary geographically and temporally depending on the model and methodology used. Trying to identify an exact impact at a particular place and time remains difficult, despite advances in modeling efforts over the past half-century. Accounting for these uncertainties, Reclamation and its stakeholders used a scenario planning approach that encompasses the estimated range of future planning conditions.

Significant potential sources of uncertainties include:

- [I would include a brief list based on the Uncertainty discussions in the various chapters (as modified).
- As the first bullet, I would nominate the following: "GCMs perform better at the global rather than regional or basin levels. Moreover, based on preliminary information (~15 years' worth of data), GCM estimates of the rate of global warming may be running too high. However, the use of bias corrected models may reduce, if not eliminate, some of the systematic biases."]
- Another bullet: "The modeling effort did not account for changes in the composition of vegetation or the direct effects of CO2. The latter includes potential increases in photosynthetic rates and water use efficiency in vegetation. An increase in water use efficiency might help reduce agricultural water demand, and, unless overwhelmed by an increase in production, it might increase runoff, soil moisture and groundwater recharge."

More detailed information about uncertainties related to each part of the study is available in the Klamath River Basin Study Full Report.

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17-01174_013157;17-01174_013157;17-01174_013158;17-01174_013159;17-01174_013160;17-01174_013161;1...

RECLAMATION

Managing Water in the West

Final Report

Klamath River Basin Study

Technical Memorandum 86-68210-2016-06

Prepared by:

Klamath River Basin Study Technical Working Group

U.S. Department of the Interior
Bureau of Reclamation

State of California
Department of Water Resources

State of Oregon
Water Resources Department

March 2016

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Abbreviations and Acronyms

AF	acre-feet
AFY	acre-feet per year
BA	Biological Assessment
Basin Study	Klamath River Basin Study
BCSD	bias corrected and statistically downscaled
BiOp	Biological Opinion
BLM	Bureau of Land Management
CDFG	California Department of Fish and Game (became CDFW in 2013)
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
CEQA	California Environmental Quality Act
cfs	cubic feet per second
CMIP3	Coupled Model Intercomparison Project, Phase 3
CMIP5	Coupled Model Intercomparison Project, Phase 5
COPCO	California Oregon Power Company
CRLE	complementary relationship lake evaporation
CRS	Congressional Research Service
CT	central tendency
CVP	Central Valley Project
degrees C	degrees Celsius
degrees F	degrees Fahrenheit
DPS	distinct population segment
DRI	Desert Research Institute
EIS/EIR	environmental impact statement/environmental impact report
ENSO	El Niño/southern oscillation
EOM	end of month
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ET	evapotranspiration
ET_c	crop evapotranspiration
ET_o	reference evapotranspiration
FAO	Food and Agriculture Organization of the United Nations

FERC	Federal Energy Regulatory Commission
GCM	general circulation model
GDD	growing degree days
gpcd	gallons per capita per day
HD	hot-dry
HDe	ensemble hybrid delta method
HUC	hydrologic unit code
HW	hot-wet
Interior	U.S. Department of the Interior
IPCC	Intergovernmental Panel on Climate Change
KAF	thousands of acre-feet
KBPM	Klamath Basin Planning Model
KBRA	Klamath Basin Restoration Agreement
KHSA	Klamath Hydropower Settlement Agreement
LKNWR	Lower Klamath National Wildlife Refuge
M&I	municipal and industrial
MODFLOW	modular finite-difference flow (model)
MWAT	maximum weekly average temperature
NEPA	National Environmental Policy Act
NIWR	net irrigation water requirement
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWR	National Wildlife Refuge
OWRD	Oregon Water Resources Department
PDO	Pacific decadal oscillation
PDSI	Palmer drought severity index
P_e	effective precipitation
PET	potential evapotranspiration
P.L.	Public Law
PM	Penman Monteith dual crop coefficient method
Prcp	mean annual precipitation
Project	Reclamation's Klamath Project
PRMS	precipitation runoff modeling system
Reclamation	Bureau of Reclamation
RBM10	River Basin model-10
RO	runoff

SECURE	Science and Engineering to Comprehensively Understand and Responsibly Enhance
SONCC ESU	Southern Oregon/Northern California Coast Ecologically Significant Unit
SWE	snow water equivalent
Tavg	mean daily average temperature
T_{max}	maximum daily air temperature
T_{min}	minimum daily air temperature
TMDL	total maximum daily load
TWG	technical working group
UKL	Upper Klamath Lake
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIC	variable infiltration capacity (model)
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WD	warm-dry
WW	warm-wet
WWCRA	West-Wide Climate Risk Assessments

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Chapter 1
Klamath River Basin Study Introduction

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Contents

Figures

Tables

Chapter 1 Introduction

1.1 Background

The Klamath River Basin is the second largest watershed in the State of California (approximately 15,700 square miles), after the Sacramento River Basin (approximately 27,900 square miles; see Figure 1-1). Approximately 60 percent of the watershed is public land (U.S. Geological Survey [USGS], 2007). It supports habitats and numerous fish and wildlife species in addition to supplying water for agriculture, hydropower, recreation, the environment, and tribal, municipal, industrial, and domestic uses. The watershed is divided by the Cascade and Siskiyou Mountains, which create two distinct climates: an arid climate in the upper basin, generally east of the mountains, and a maritime climate in the lower basin. The upper portion of the basin covers approximately 38 percent of the watershed but contributes only 12 percent of the entire watershed's annual flow (Congressional Research Service [CRS], 2005). The lower portion of the basin covers approximately 62 percent of the watershed, yet contributes 88 percent of the watershed's annual flow. The primary tributary inflows are located in the Lower Klamath Basin and include the Shasta, Scott, Salmon, and Trinity Rivers.

The Klamath River Basin has a history of complex water management challenges, dating back more than a century. In large part, these challenges relate to the competing needs of the various mainstem users, irrigation diversions on the Scott, Shasta, and Trinity Rivers (tributaries to the Klamath), and the construction of six mainstem dams (see Figure 1-1), which have altered the natural flow and nutrient and sediment regimes in the river and have inhibited upstream passage of migratory fish above Iron Gate Dam (river mile 190).

Managers of natural resources in the Klamath River Basin have long called for a comprehensive and integrated approach to water management. In 2008, the National Research Council reported that "the most important characteristics of research for complex river-basin management were missing for the Klamath River: the need for a 'big picture' perspective based on a conceptual model encompassing the entire basin and its many components" (Thorsteinson et al., 2011).

[1] Figure 1-1 produced by Michael Neuman, Klamath Basin Area Office of the Bureau of Reclamation

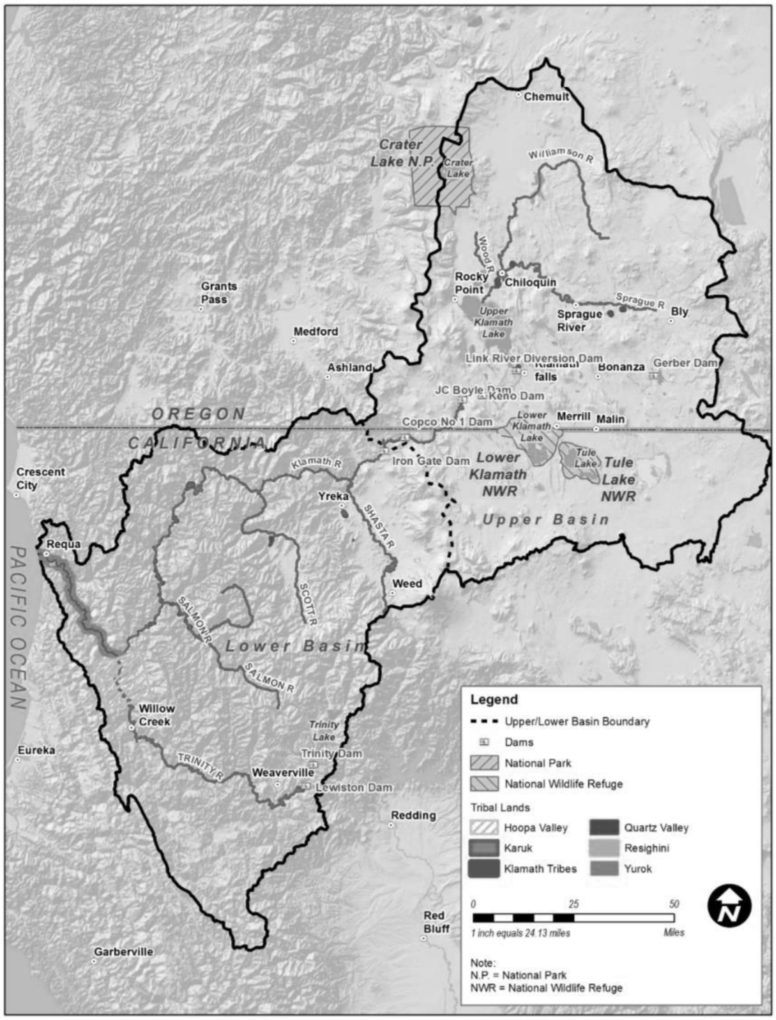

Figure 1-1. Klamath River Basin overview map

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to achieve future water security. The Bureau of Reclamation (Reclamation) serves as the U.S. Department of the Interior's (Interior) primary water management agency. It developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (Public Law

[P.L.] 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program, which was developed as a result. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management.

The Klamath River Basin Study commenced in September 2012. Non-federal cost share partners for the study include the California Department of Water Resources (CDWR) and the Oregon Water Resources Department (OWRD). It should be noted that the Klamath River Basin Study:

- Does not require federal or state environmental review
- Does not contain recommendations for action
- Is not a decisional document

This first chapter of the Klamath River Basin Study provides an overview of the basin, identifies the study purpose, scope, and objectives, and discusses the overall process of the basin study. This chapter also outlines the collaboration and outreach process, which is a significant component of the Klamath River Basin Study.

1.2 Purpose, Scope, and Objectives of the Study

The purpose of the Klamath River Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances. Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessment (WWCRA) but contain additional information, if available (refer to Reclamation [2011d] for water supply assessment; demand assessment is currently under development). The WWCRA is an ongoing complementary activity in the Basin Studies Program in which Reclamation is developing a comprehensive and consistent set of hydro-climate data resources west-wide by incorporating the best available science. These data resources provide a baseline for climate change adaptation planning.

More specifically, basin studies seek to build on existing knowledge through studies, reports, and stakeholder collaboration. The following objectives are key components of each basin study:

- Assess current and projected future water supply
- Assess current and projected future water demand
- Evaluate current and projected future system reliability with respect to chosen performance measures

- Identify and evaluate potential adaptation strategies that may reduce any imbalances

The Klamath River Basin has a long history of water management challenges. Numerous studies have been conducted that evaluate the projected impacts of climate change in the region (e.g., Reclamation, 2011; Risley et al., 2012; Oregon Climate Change Research Institute, 2010; National Center for Conservation Science and Policy, 2010) and explore potential adaptation strategies (e.g., increase offstream storage) that may mitigate the impact. The Klamath River Basin Study seeks to add value to previous and ongoing work in the watershed by evaluating water supply and demand together in a modeling and decision support framework that allows for exploration of a range of management strategies.

1.3 Location and Description of the Study Area

1.3.1 Geographic and Geologic Setting

The Klamath River flows over 253 miles from its headwaters north of (and including part of) Crater Lake National Park in Oregon to its outflow at the Pacific Ocean in Requa, California (Figure 1-1). The Klamath River Basin includes all or parts of Klamath, Lake, Modoc, Siskiyou, Del Norte, Trinity, and Humboldt Counties. Five national forests intersect the Klamath River Basin: Six Rivers, Klamath, Shasta-Trinity, Modoc, and Winema. The Klamath River Basin also contains a substantial amount of land managed by the Bureau of Land Management. From a water management perspective, the basin is divided into two regions, the dividing line being approximately at the location of Iron Gate Dam: the upper portion (hereafter referred to as "Upper Klamath Basin"), and the lower portion (hereafter referred to as "Lower Klamath Basin"). The Upper Klamath and Lower Klamath Basins generally have differing climates and management challenges.

The Klamath River begins in Lake Ewauna, south of Upper Klamath Lake and the city of Klamath Falls, Oregon. The river reach between Upper Klamath Lake and Lake Ewauna is called the Link River. Contributing flows to Upper Klamath Lake originate from the slopes of the Cascade Range and Siskiyou Mountains. The primary tributaries to the Klamath River above Upper Klamath Lake include Wood River to the north, Williamson River to the north, Sprague River to the east, and inflows from the eastern flank of the Cascades. The Klamath River flows southwesterly into California and then west to the Pacific Ocean. The major tributaries entering the mainstem river include the Shasta, Scott, Salmon, and Trinity Rivers. These four rivers all join the Klamath River downstream of Iron Gate Dam and provide 44 percent of the mean annual flow, which heavily influences the hydrology of the Klamath River Basin.[2] The mean annual flow of

[2] Major tributary flow as percentage of Klamath River flow (44%) was reported by BLM (1990) and verified by computing the percentage on a mean annual basis (water years 1951-2012) using the

the Klamath River is about 17,900 cubic feet per second. Eleven miles of the Klamath River between the J.C. Boyle Powerhouse and the California-Oregon border were designated as "scenic" in 1994 under the National Wild and Scenic Rivers System (P. L. 90-452, October 2, 1968). The mainstem lower Klamath River from Iron Gate Dam to the Pacific Ocean, as well as reaches of the Scott River, Salmon River, Wooley Creek (tributary of the Salmon River), and Trinity River, are classified under the National and California Wild and Scenic River Systems (California classifications according to Public Resources Code Section 5093.50 et seq.). These classifications include "wild," "scenic," and "recreational."

The Klamath River contains six mainstem dams (Table 1-1). Link River Dam, at river mile 253 in Oregon, maintains Upper Klamath Lake levels and largely replaced a natural reef that historically formed the lake. Keno Dam, at river mile 232 in Oregon, replaced a natural reef which historically regulated water surface elevations of Lower Klamath Lake (Reclamation, 2005). The remaining mainstem dams were constructed where the Klamath River enters sections of the canyon through the coastal mountain range. These dams were primarily constructed for hydropower production and include: California Oregon Power Company (COPCO) 1 dam at river mile 197 (California); COPCO 2 dam at river mile 198 (California), which was constructed to reregulate flows out of COPCO 1; J.C. Boyle Dam at river mile 227 (Oregon), which was constructed primarily for producing peaking power upstream of the COPCO dams; and, Iron Gate Dam at river mile 190 (California). PacifiCorp (owned by MidAmerican Energy Holdings Company) owns and operates the hydropower producing facilities on the Klamath River under Federal Energy Regulatory Commission license 2082 and provides most of the Klamath River Basin's power (CDWR, 1960).

The Upper Klamath Basin once held pluvial Lake Modoc at an elevation of about 4,200 feet above sea level with an estimated 400 miles of shoreline and 1,000 square miles of surface area. As temperatures warmed during the Late Pleistocene, only Tule Lake, Lower Klamath Lake, and Upper Klamath Lake remained. Parts of the bed of Lake Modoc became Langell Valley and Poe Valley (Beckham, 2006). Lower Klamath and Tule Lakes are discussed further in Section 1.4.2.1. Upper Klamath Basin.

The Klamath River Basin covers three geologic provinces from east to west: the Modoc-Oregon Lava Plateau, the Cascade Range, and the Klamath Mountains. The Modoc-Oregon Lava Plateau includes nearly all of the Klamath River Basin in California east of (and including) Butte Valley. Downstream from Iron Gate Dam and for most of the river's length to the Pacific Ocean, the river maintains a steep, coarse-grained, confined channel. From Iron Gate east to the Oregon-

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following streamflow gages: 1) USGS 11530500 Klamath R. nr Klamath, CA; 2) USGS 11522500 Salmon R. at Somes Bar, CA; 3) USGS 11519500 Scott R. nr Fort Jones, CA; 4) USGS 11517500 Shasta R. nr Yreka, CA; 5) USGS 11530000 Trinity R. at Hoopa, CA. This reported value is based on a simplified water balance which may not be an accurate accounting of the contribution of the four major tributaries to flow in the Klamath River at Klamath, CA.

California state line, the river is predominantly nonalluvial and sediment-supply-limited. The Cascade Range forms a north-south belt through the basin, extending from beyond Crater Lake on the north to Mount Shasta on the south. It is bounded in part on the east by the western edge of Butte Valley and on the west by the western edge of Shasta Valley. The Klamath Mountains province includes the entire remainder of the basin lying west of the Cascade Range (CDWR, 1960).

Table 1-1. Summary of Klamath Basin dams

Dam Name	Location	Klamath River Mile	Year Completed	Reservoir Capacity (acre-feet)	Purpose
Upper Klamath Basin					
Clear Lake[1]	Lost River	NA	1910	527,000	Irrigation
COPCO 1	Klamath River	197	1918	6,235	Hydropower
Link River	Klamath/Link River	253	1921	873,000	Control UKL level
COPCO 2	Klamath River	198	1925	73	Hydropower
Gerber[1]	Miller Creek	NA	1925	94,300	Irrigation
JC Boyle	Klamath River	227	1958	3,377	Peaking power
Iron Gate	Klamath River	190	1962	58,000	Hydropower
Keno	Klamath River	232	1966	18,500	Hydropower, recreation
Lower Klamath Basin					
Dwinnell Dam[2]	Shasta River	NA	1928	50,000	Water supply
Lewiston[2]	Trinity River	NA	1967	14,660	CVP water supply
Trinity	Trinity River	NA	1962	2,400,000	CVP water supply

Notes: CVP = Central Valley Project. UKL = Upper Klamath Lake

[1] Clear Lake and Gerber Reservoirs are briefly discussed in Section 4.2.1, Upper Klamath Basin.

[2] Dwinnell and Lewiston Dams are briefly discussed in Section 4.2.2, Lower Klamath Basin.

1.3.2 Historical Climate and Hydrology

Mean annual precipitation in the basin ranges from as little as 10 inches at lower elevations to more than 70 inches in the mountains to the west (Reclamation, 2011a). About two-thirds of the precipitation falls as snow between October and March. The annual long-term average snowfall in Klamath Falls is about 41 inches per year. Crater Lake (62 miles northwest of Klamath Falls) averages about 521 inches of snow annually.

Historical runoff in the Klamath River Basin is highly variable from year to year. Although precipitation predominantly occurs in the winter months, water percolates and moves through the volcanic soil such that monthly discharge is almost constant in the Upper Basin (CDWR, 1960). Under natural conditions the Upper Klamath Basin area lakes have a significant regulatory effect on the river (CDWR, 1960). A review of historical information in the Klamath River Basin

suggests that, although there may be trends in historical runoff at some sites, they are relatively weak or insignificant (Reclamation, 2011c).

All precipitation and snowmelt in the Shasta River watershed (draining to the Klamath River) percolates into the volcanic soil and appears in springs or discharges directly from the ground water into the Shasta River. The only significant surface runoff from the Cascade Range along the eastern edge of Shasta Valley occurs in the Little Shasta River (CDWR, 1960). In the Scott, Salmon, Trinity, and other tributaries of the lower Klamath River, runoff is a function of precipitation and snow storage (CDWR, 1960).

Since 1900, temperatures in the Pacific Northwest have increased by 1.0 degree Celsius, which is 50 percent greater than the global average, as reported by other studies (Knowles et al., 2007; Regonda et al., 2005; Mote, 2008). Further, the Klamath River Basin, like the western United States overall, has experienced a general decline in spring snowpack, reduction in the amount of precipitation falling as snow in the winter, and earlier snowmelt runoff between the mid- and late-20th century. Although observed trends of temperature, precipitation, snowpack, and streamflow in the western United States might be partially explained by anthropogenic influences on climate (Barnett et al., 2008; Pierce et al., 2008; Bonfils et al., 2008; Hidalgo et al., 2009; and Das et al., 2009), these changes are difficult to distinguish from natural climate variability (Villarini et al., 2009), particularly in the case of precipitation (Hoerling et al., 2010). Similarly, future projections of climate over the next 30 to 50 years indicate that the Klamath River Basin will continue to experience warming, as well as increased winter precipitation and decreased summer precipitation. Natural modes of variability like the El Nino/Southern Oscillation and the Pacific Decadal Oscillation (PDO) will continue to influence these general trends (Thorsteinson et al., 2011).

1.3.3 Vegetation, Wildlife, and Fish

The Klamath Basin is home to a diverse range of plant species. Tree species include willows, pines, ash, oak, cedar, juniper, alder, and birch. Shrubs range from poison oak and sumac to dogwood, manzanita, honeysuckle, currant, mock orange, ninebark, plum, chokecherry, crabapple, snowberry, sagebrush (several varieties), and Oregon grape. Hundreds of indigenous herbaceous plants grow in this region including orchids, lilies, paintbrushes, grasses, ferns, horsetails, and lichens (Beckham 2006).

Wildlife includes numerous mammals, birds, fish, amphibians, and reptiles. Large animals include black bear, black-tailed deer, mule deer, elk, and mountain lion. Smaller mammals range from beaver, ermine, and fisher to bats, river otter, foxes, squirrels, chipmunks, rabbits, shrews, woodrats, and voles. Numerous reptiles live in the area and include the western rattlesnake, garter snake, and pond turtle. Raptors, game birds, woodpeckers, and other water and land birds are at home in this setting. The Upper Klamath Basin is a part of the Pacific Flyway where hundreds of thousands of migrating birds stop to rest. The U.S. Fish and Wildlife

Service (USFWS) listed the northern spotted owl as threatened under the Endangered Species Act (ESA) in 1990, the shortnose and Lost River suckers as endangered in 1988, and the bull trout as threatened in 1999. The National Marine Fisheries Service (NMFS) listed the Southern Oregon/Northern California Coast Ecologically Significant Unit (SONCC ESU) of coho salmon as threatened in 1997 and reconfirmed the listing in 2005, and listed critical habitat for the threatened distinct population segment of the Pacific Eulachon in 2011, which includes the Klamath River estuary. In total three plant, eight fish, seven whale, four turtle, four bird species, and one sea lion in the vicinity of the Klamath River are ESA listed; however, the suckers, coho, and bull trout are most often affected by water management practices.

The Lower Klamath and Tule Lake National Wildlife Refuges (NWR), located in the upper Klamath Basin of Oregon and California, encompass approximately 46,700 and 39,100 acres, respectively (Risley and Gannett, 2006). According to the study by Risley and Gannett (2006), mean annual (2003–2005) water use for the Lower Klamath and Tule Lake NWRs was approximately 124,000 and 95,900 acre-feet, respectively, including precipitation and water deliveries.

The Klamath River is home to numerous resident and migrating fish species. Resident fish resources include redband trout and rainbow trout in the mainstem Klamath River (Beckham, 2006). The shortnose and Lost River sucker reside in the Upper Klamath Basin. Historically, the Klamath River was the third most productive river for salmon in the continental United States. Spring Chinook, fall Chinook, and coho salmon, as well as steelhead, spawn in reaches of the Klamath River and its tributaries.

The six mainstem Klamath River dams were all initially constructed without fish passage; therefore, anadromous fish were cut off from the Upper Klamath River reaches above the COPCO 1 dam site in 1918. They were cut off from an additional 7 miles of river, upstream of Iron Gate Dam (river mile 190) in 1962. Two primary hatcheries were established in the Klamath Basin for raising coho, Chinook, and steelhead: the Trinity River Hatchery, built in 1963, and the Iron Gate Hatchery, built in 1966 (CRS, 2005).

Although the COPCO expressed willingness to construct a single fish ladder at COPCO 1, they and the State of California agreed to close off all runs of anadromous fish and to compensate for the loss of natural runs by stocking the lakes and streams of the Klamath Basin with hatchery-raised fish. Most fishery biologists at the time did not believe fish migration over COPCO 1 via fish ladder was feasible (Beckham, 2006).

Because the SONCC ESU of coho salmon is listed as threatened under the federal ESA, the commercial harvest of these fish has been prohibited. In addition, the Chinook salmon harvest has been restricted in northern California and southern Oregon marine waters for several years to allow the Klamath River to attain the Pacific Fishery Management Council's spawning escapement goals (CRS, 2005).

In 2006 the lack of returning adult salmon to the Klamath River resulted in the closure of several hundred miles of Pacific Coast salmon fisheries (USGS, 2007). Each summer large blooms of the blue-green algae Aphanizomenon flos-aquae in the Upper Klamath Lake lead to low dissolved oxygen and lethal conditions (in part because they produce harmful toxins) for endangered suckers. Major die-offs of suckers occurred in 1986, 1995, 1996, and 1997 (USGS, 2007).

1.4 Present Water and Related Resources Development

1.4.1 History of Settlement

Indigenous people have inhabited the Klamath River Basin since time immemorial (Beckham, 2006). Currently the basin is home to six federally recognized Indian Tribes: the Yurok Tribe; Hoopa Valley Tribe; Karuk Tribe; the Klamath Tribes, comprised of Klamath, Modoc, and Yashookin; Quartz Valley Indian Community; and Resighini Rancheria (77 FR 47868). Numerous additional native groups that are not federally recognized, such as the Shasta people, inhabit parts of Northern California and Southern Oregon. Although they are not federally recognized, some of them have been inducted into the Karuk Tribe (Beckham, 2006).

The Klamath River and canyon are considered sacred by the native tribes (Bureau of Land Management, 1990). The study area includes burial grounds of the Shasta people and their principal ceremonial areas, which are used for spiritual and educational purposes. Native tribes also value the canyon for other important cultural activities. The river area has long been used for fishing, gathering, and hunting; as a meeting place between the area's various tribes and bands; as shared fishing villages; and as a pathway for inter-tribal exchange and communication (Bureau of Land Management, 1990).

Initial Euro-American explorers in the Klamath Basin included fur traders from the Hudson Bay Company as well as surveyors from the United States Navy and Army and emigrant travelers. Settlement began in the mid-1800s, with the discovery of gold in the Lower Klamath Basin, below the Shasta River confluence (Beckham, 2006). Long-term settlement solidified with the passing of the Homestead Act in 1862, which allowed citizens (or those intending to be naturalized) over 21 years old to settle on 160 acres (or less) of land. Railroad development and logging came later due to the rugged terrain in the southern Cascades and Siskiyou Mountains (Beckham, 2006; CDWR, 1960). The Reclamation Act of 1902 initiated a number of federal irrigation projects across the western United States to manage already existing irrigation and to expand settlement in the arid west. Development of Reclamation’s Klamath Project is described in Section 1.4.2. Water Resources Development.

At one time the Klamath watershed was one of the greatest timber-producing regions in the nation (CDWR, 1960). The Klamath River and tributaries were historically used to transport logs to mill sites. For example, in the late 1800s the

Klamath River Improvement Company drove logs from the Spencer Creek area (west of Keno, Oregon) to the California-Oregon state line. Splash dams made of wood and rock were historically used to create surges of water that would facilitate transportation of logs downstream (Beckham, 2006). The timber industry continues to be a significant portion of the regional economy, despite declines since the late 1970s and early 1980s.

Recreational facilities like campgrounds and trails have drawn many tourists annually into the area including Crater Lake, the Modoc Lava Beds, the Trinity Alps, Marble Mountain Primitive Areas, and the coastal redwoods (CDWR, 1960). River reaches between JC Boyle Dam and Iron Gate Dam, as well as below Iron Gate Dam, are major destinations for commercial and private white-water rafting and kayaking (CRS, 2005).

1.4.2 Water Resources Development

1.4.2.1 Upper Klamath Basin

The passing of the Reclamation Act in 1902, in addition to legislation passed by Oregon and California to transfer ownership of land to the federal government, led to the development of the Klamath Irrigation Project (Figure 1-2). The initial project was completed in 1907. By 1924 portions of Lower Klamath and Tule Lakes were drained to uncover additional desirable farmland. In addition, dams were built to facilitate diversions and produce hydropower for the region (Reclamation, 2000).

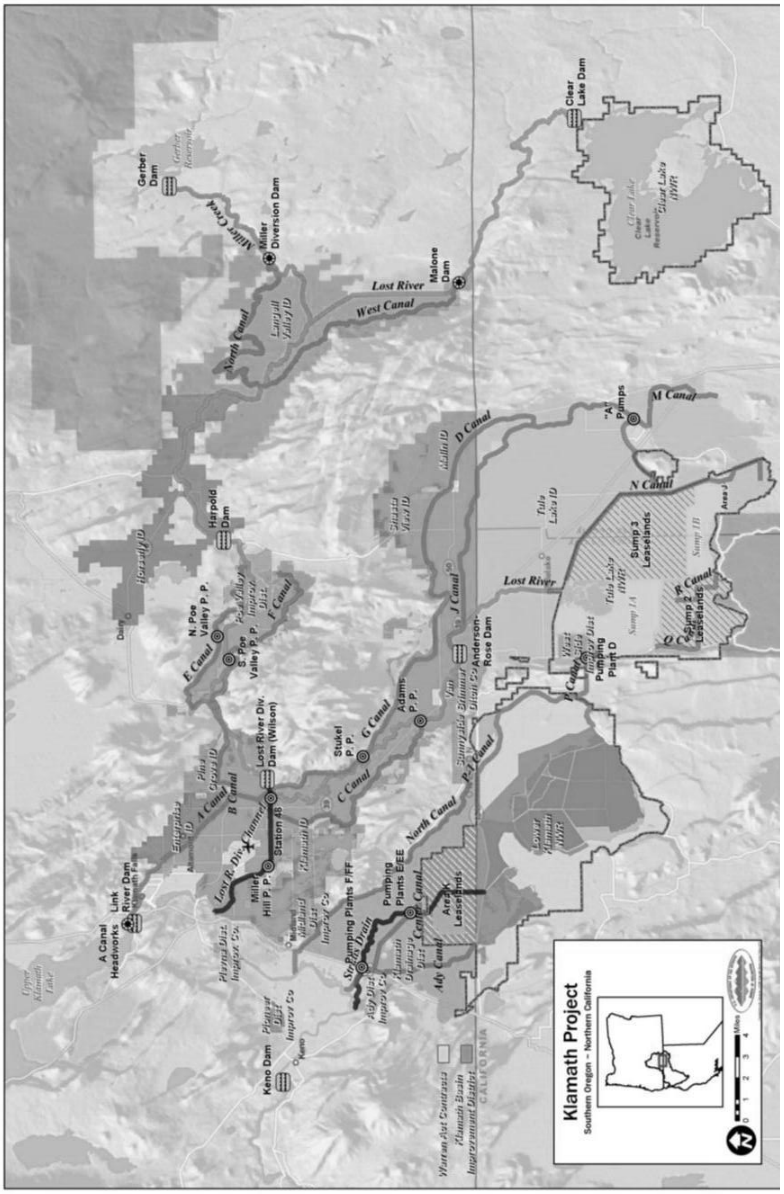

Figure 1-2. Klamath Irrigation Project map

Reclamation's Klamath Project is primarily fed by Upper Klamath Lake and the Lost River system, which includes Clear Lake Reservoir on the Lost River and Gerber Reservoir on tributary Miller Creek (refer to Table 1-1). Releases from Clear Lake and Gerber Reservoirs are delivered to the east side of the Klamath Project to irrigate lands in Langell Valley. The Lost River also receives water from Bonanza Springs located in Bonanza, Oregon. During the irrigation season, flows from the springs in the Lost River may be available for irrigation (Reclamation, 2012).

Prior to development of Reclamation's Klamath Project, the Klamath and Lost River Basins were linked by a flood channel, the Lost River Slough, which allowed water from the Klamath River to enter the Lost River and flow to Tule Lake during high runoff conditions. The two watersheds are now linked by the Lost River Diversion Channel, which facilitates water management and surface delivery of water to the Klamath Project, Tule Lake NWR, and Lower Klamath NWR. During the wet periods of the year water is diverted to the Klamath River; during the drier periods irrigation water is diverted to the Lost River from the Klamath River for irrigation needs (Reclamation, 2011a).

Reclamation's Klamath Project has historically included approximately 254,000 acres of land. It provides water to approximately 1,400 farms covering about 200,000 acres as well as about 27,000 irrigable acres of refuge lands. Principal crops raised on Reclamation's Klamath Project include alfalfa, irrigated pasture, small grains, and potatoes. Onions, horseradish, mint, and strawberry plants are also grown (Reclamation, 2011a; CRS, 2005). In 2011 the Klamath Project's gross crop values were estimated at $204 million (Reclamation, 2012). Water released from one of the project's storage reservoirs may be reused several times before it is returned to the Klamath River. Some of the return flows provide water to the Lower Klamath NWR and the Tule Lake NWR. Excess water and water released from NWR lands is returned to the Klamath River via the Klamath Straits Drain.

Additional irrigation in the Upper Klamath Basin occurs in Butte Valley, California, where the Butte Valley Irrigation District supplies water for approximately 4,000 irrigated acres in the southern end of the valley (CDWR, 1960).

1.4.2.2 Lower Klamath Basin

The Lower Klamath Basin also supports agriculture, but to a lesser extent than the Upper Basin. As of 1997 the number of Lower Basin farms was about 40 percent of those found in the Upper Basin, and agricultural production was estimated to be less than half the value of Upper Basin agriculture ($114 million compared to $283 million) (CRS, 2005).

There are four organized irrigation districts in the Shasta Valley (approximately 10,000 irrigated acres). The Dwinnell Dam, forming Dwinnell Reservoir, or Lake Shastina (Table 1-1), is maintained by the Montague Water Conservation District,

the largest of the Shasta watershed irrigation districts. About 24,000 acres within the Shasta Valley, but lying outside the irrigation districts, are served by individual diversions from various streams (CDWR, 1960). The only known trans-boundary diversion into the Klamath River Basin is from the Sacramento River Basin in California. About 4,000 acre-feet seasonally are diverted into the basin and used for irrigation purposes in the extreme southern end of Shasta Valley.

The Scott River Irrigation District is the single major organized water provider in Scott Valley, California. The district serves approximately 3,500 irrigated acres (CDWR, 1960). Surface water supplies for irrigation are supplemented by pumping of ground water. Most of the irrigated area in Scott Valley, however, lies to the west of the river and is supplied by individual development (CDWR, 1960).

There are additional small cultivated areas in the Lower Klamath Basin, including Hayfork Valley, a portion of the Hoopa Valley Indian Reservation on the Trinity River, and small areas in the vicinity of Lewiston and Seiad Valley (CDWR, 1960).

The Trinity River, the lowermost tributary of the Klamath River, provides water to the California Central Valley Project (CVP), another federal project (CRS, 2005). The Trinity River Division of the CVP was completed in 1964. The Trinity River is the largest tributary of the Klamath River. It enters the Klamath River about 20 miles upstream of its mouth at the Pacific Ocean. The Trinity River Diversion diverts and exports water from the Trinity River system by means of dams, reservoirs, tunnels, and power plants to the Sacramento River (CRS, 2005). At one time, nearly 90 percent of the water in the Trinity River was exported to the Central Valley (CRS, 2005). However, a 2000 Record of Decision reduced that percentage to restore fisheries (CRS, 2005). Lewiston and Trinity Dams (refer to Table 1-1) had cut off 109 miles of anadromous fish habitat on the Trinity River (CRS, 2005).

There are two additional trans-boundary diversions from the Klamath Basin, both in the western portion of the Upper Klamath Basin. One diversion is made from Keene Creek by way of Hyatt Prairie Reservoir, and the other diversion is made from Fourmile Creek by way of the Cascade Canal. This diverted water supplies irrigate lands adjacent to Ashland and Medford in the Rogue River Basin (CDWR, 1960).

1.4.3 History of Water Management Challenges

The Klamath River Basin, like many watersheds in the arid western United States, suffers from use beyond the sustainable capacity of the basin (i.e., over-appropriation). This may be due to a number of factors. First, there are physical constraints in the watershed that are unique to the Klamath Basin. Second, federal and state policies with respect to indigenous people and the environment have not been consistent over time, which has contributed to complex

socioeconomic challenges. Finally, regulatory constraints exist in terms of conflicting state and federal policies. This section will briefly describe these constraints as a way of identifying historical and current water management challenges in the basin and to emphasize the need for a comprehensive Klamath River Basin Study to evaluate any identified current and/or projected future imbalances in water supply and demand.

The Klamath River Basin is unique in that the largest agricultural development in the basin occurs in the Upper Klamath, which receives disproportionately low precipitation compared with the rest of the basin. The Upper Klamath Basin has limited suitable sites for reservoir storage; therefore, water users are subject to the effects of climate variability. For example, Upper Klamath Lake, which is the primary source of water for Reclamation's Klamath Project, is relatively shallow and has little carryover storage from year to year, which makes the project highly dependent on current precipitation and snowmelt for water supply (CRS, 2005).

Implementation and enforcement of state and federal water allocation policies has been a challenge. The Klamath River Compact (ORS 542.620; CA Water Code § 5900 et seq.; P.L. 85-222) between California and Oregon was ratified by the states and consented to by the United States in 1957, giving domestic and irrigation users in the Klamath River Basin preference for applications for higher use of water supplies over applications for lower use supplies, defined as recreation, industrial, hydropower, and other uses. Water rights adjudication in California was completed for the Shasta River Basin in 1932 and for the Scott River Basin in 1980, but the mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court, demarking a significant milestone in determining the water rights of the Upper Klamath Basin.

The United States must provide sufficient water to sustain and protect Indian Trust Assets, which include sufficient water to meet treaty rights such as hunting, gathering, and fishery purposes. The Klamath Tribes were terminated in 1954 (Klamath Termination Act, P. L. 587) and then regained federal recognition in 1986. As a result, the Klamath Tribes lost designated reservation land. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the Klamath Treaty of 1864, which may significantly affect water management in the Upper Klamath Basin. Lower Klamath NWR and Tule Lake NWR rely on water from Reclamation's Klamath Project. These refuges have received lower priority for water than irrigators. However, the Lower Klamath NWR (established in 1908) may have federal reserved rights which would advance their priority (CRS, 2005).

Endangered species issues have been an integral component of operating decisions for Reclamation's Klamath Project since the USFWS listed the shortnose and Lost River suckers as endangered in 1988 and the NMFS listed the SONCC ESU coho salmon as threatened in 1997 (CRS, 2005). Management

challenges associated with opposing water needs and policies are illustrated by the events that took place in the early 2000s (described briefly below), which resulted in the largest fish die-off ever recorded in the Klamath River and severe curtailment of irrigation deliveries to Klamath Project irrigators, resulting in economic hardship.

Reclamation is required to comply with the ESA by consulting on the ongoing operations of the Klamath Project with the USFWS and NMFS (the agencies with delegated authority to implement the ESA) to ensure that its operations do not jeopardize listed species or listed or proposed critical habitat. The USFWS has jurisdiction over inland fish and terrestrial species (shortnose sucker, Lost River sucker, and proposed critical habitat for both sucker species). The NMFS has jurisdiction over marine species and anadromous fish (e.g., SONCC ESU coho salmon). In early 2001 a federal district court faulted Reclamation for failing to formally consult with NMFS on the effects of water storage and diversion on downstream coho salmon under its 2000 operating plan, and prohibited Reclamation from making further diversions until it formally consulted on its next (2001) annual plan. Reclamation prepared an operation plan for 2001 which was forecast to be one of the driest years of record. Reclamation prepared a biological assessment (February 13, 2001) which covered operations until April 1, 2001. In April 2001, the USFWS and NMFS each issued final Biological Opinions concluding that Reclamation's proposed operation of the Klamath Project for 2001 would jeopardize the two species of suckers and the population of coho salmon, and it would harm, but not jeopardize, the continued existence of bald eagles. NMFS recommended release of additional water from Upper Klamath Lake for coho salmon, while USFWS simultaneously recommended maintaining higher lake levels. Because of severe drought conditions, there was not enough water to implement both Biological Opinions simultaneously, even without providing irrigation water for farmers. A judge's order prevented Reclamation from fulfilling water orders under contracts to the irrigators whenever flows dropped below the minimum flows recommended in the 2001 NMFS Biological Opinion (Reclamation, 2011e).

Reclamation announced its response on April 6, 2001, implementing proposed alternatives that severely limited the delivery of irrigation water. For the 2001 water year, Reclamation stated that the normal deliveries would be available for lands receiving water from Clear Lake and Gerber Reservoirs (70,000 to 75,000 acre-feet), but no water would be available from Upper Klamath Lake for deliveries to irrigators or to the Lower Klamath NWR (CRS, 2005). Water conservation measures and higher than expected lake levels later in the summer prompted the Secretary of the Interior to announce that up to 75,000 acre-feet would be released from Upper Klamath Lake to assist farmers. However, this came too late in the season to provide significant assistance.

The National Research Council reviewed the scientific decisions of the controversial 2001 Biological Opinions. The National Research Council Committee concluded that scientific data were insufficient to support the Upper

Klamath Lake level management regimes proposed by the 2001 USFWS Biological Opinion. Although Reclamation's written response to the USFWS 2001 Biological Opinion expressed disagreement with the Biological Opinion's conclusions, Reclamation agreed to not deliver any water from Upper Klamath Lake to Klamath Project water users and NWRs from April through September 2001. Water from Gerber and Clear Lake Reservoirs was used for irrigation on and to meet evaporative losses on the NWR. Releases from Upper Klamath Lake were made to meet minimum stream flows; however, the project was operated to modified minimum elevations for Upper Klamath Lake, which deviated from the minimums prescribed in the USFWS Biological Opinion. An above average number of Chinook salmon entered the Klamath River that August and September, while river flows were unusually low due to drought conditions and unusually warm temperatures. These conditions contributed to the death of more than 33,000 adult salmon (primarily Chinook but also coho, steelhead, and others) due to epizootic disease in the first 40 miles of the river (California Department of Fish and Game, 2004; CRS, 2005).

Several ESA consultations since the early 2000s have affected Klamath Project operations. The most recent to date (and to which current operations adhere) is the 2012 Biological Assessment and 2013 Biological Opinion (BiOp) jointly prepared by the USFWS and NMFS on the Lost River and shortnose sucker, the SONCC coho salmon, the Southern distinct population segment (DPS) green sturgeon, and the Southern DPS eulachon, which directs the operations throughout the Upper Klamath Basin and influences river flows from Link River Dam to the Klamath Estuary. The Biological Assessment and Joint BiOp were completed following a multi-year consultation effort between Reclamation, the USFWS, and NMFS to develop a new long-term operations plan that would "allow Reclamation to continue to operate the Klamath Project to store, divert, and convey water to meet authorized Klamath Project purposes and contractual obligations in compliance with applicable state and federal law while meeting the conservation needs of affected listed species in a coordinated manner" (NMFS and USFWS, 2013).

1.5 Future Challenges and Considerations

The Klamath River Basin Study identifies and evaluates potential adaptation strategies to reduce any identified water supply/demand imbalances. Numerous studies have already identified and investigated potential adaptation strategies. To the extent possible, this study builds upon past or existing efforts and encompasses a wide range of options, perhaps even previously rejected strategies that may perform differently under a wider range of evaluation measures.

This study must also consider the regulations that are in place or in progress in the basin, including among other things total maximum daily load (TMDL) water quality criteria established in parts of the watershed, as well as past and existing restoration efforts. For example, this study considers, in a scenario context, the

ongoing negotiations of the Klamath Basin Restoration Agreement (KBRA) and Klamath Hydropower Settlement Agreement and the related Secretarial Determination Process. The following section of this report touches on these considerations in more detail and concludes with recognition of future challenges.

1.5.1 Previously Identified Management Alternatives

Numerous studies have been initiated to investigate options for increased or new storage (including groundwater), demand reduction, and habitat restoration, even before the events of 2001 and 2002. The Klamath Basin Water Supply Enhancement Act of 2000 (P.L.106-489) authorized Reclamation to study the feasibility of increasing storage capacity in the Upper Klamath Basin and Reclamation's Klamath Project through surface or groundwater supplies (CRS, 2005). Potential options were identified and developed in the 1990s through the Klamath Basin Water Supply Initiative, a public input process involving potentially affected state, local, and tribal interests as well as concerned stakeholders (for example, potential new storage in the Long Lake Valley [Reclamation, 2010]). The Initial Alternatives Information Report, Upper Klamath Basin Offstream Storage Study (Reclamation, 2011a) further investigated options including an aquifer storage and recovery groundwater option at Gerber Reservoir and a hybrid option involving aquifer storage and recovery at Clear Lake and surface storage at a new dam (to be named Boundary Dam). However, these investigations have not identified viable options from a cost/benefit perspective.

Water banking has also been proposed as a management strategy. During the water shortage of 2001, Reclamation initiated the Groundwater Purchase Program, a water bank to buy water for fish and wildlife (CRS, 2005). As part of the NMFS 2002 Biological Opinion, Reclamation could avoid jeopardizing ESA threatened coho salmon by creating and implementing a water bank. Eligible farmers could bid to irrigate their lands with groundwater from their own wells in exchange for payment, thereby freeing water from Upper Klamath Lake (CRS, 2005). These pilot water bank programs were successful in meeting NMFS Biological Opinion requirements for the 2003 and 2004 water years. Reclamation employed a combination of land idling and groundwater substitution in an attempt to meet water banking targets for 2005–2011; however, in 2006 the court eliminated the water banking requirement that was part of the NMFS 2002 Biological Opinion (Reclamation, 2011). Groundwater pumping has also been identified as a potential long-term water management strategy. Pumping groundwater provides short-term benefits, but over-drafting of aquifers has long-term consequences that are less clear (CRS, 2005).

A number of entities are undertaking specific projects to improve water quality and restore habitat. For example, the U.S. Department of Agriculture's Natural Resources Conservation Service has a Work Plan for Adaptive Management for the Klamath Basin to mitigate the effects of drought on agriculture. The core objectives of this program are: (1) decreasing water demand, (2) increasing water storage, (3) improving water quality, and (4) developing fish and wildlife habitat.

1.5.2 Development of Water Quality Criteria

Criteria for TMDLs have been established for the Klamath River Basin (including Lost River) through collaboration between the California North Coast Regional Water Quality Control Board, Oregon Department of Environmental Quality, U.S. Environmental Protection Agency (EPA) Regions 9 and 10, and contractors. The TMDLs for the mainstem Klamath River (including an implementation plan for the already approved Lost River TMDL) were approved by the California State Water Resources Control Board and EPA Region 9 in December 2010. NMFS completed its ESA consultation on the Klamath River TMDLs in December 2010 (National Oceanic and Atmospheric Administration [NOAA], 2011). The Oregon Department of Environmental Quality issued a departmental order adopting TMDLs for the listed parameters for the Upper Klamath (Link River Dam to California state line) and the Upper Lost River. The Oregon TMDLs have been submitted to EPA Region 10 for final approval. TMDLs for the Klamath River's major tributaries (Lost, Scott, Shasta, and Trinity Rivers) were previously established. Klamath River Basin TMDLs are summarized in Table 1-2. When TMDLs are developed, water quality criteria are established for sustaining fish and wildlife species, then acceptable waste load allocations are identified. In many cases existing natural conditions exceed established water quality criteria.

Table 1-2. Summary of Klamath Basin TMDLs

Sub-basin or Reach	TMDL
Sprague River, Williamson River, Upper Klamath Lake	Dissolved oxygen, chlorophyll a, pH (2002)
Lower Lost River (Oregon)	Dissolved oxygen, pH, ammonia toxicity, temperature in Lost River tributaries (2010)
Lower Lost River (California)	Nutrients, pH (2008) Temperature (2006)
Klamath River (Oregon)	Dissolved oxygen, pH, ammonia toxicity, temperature, chlorophyll a (2010)
Klamath River (California)	Nutrients, temperature, dissolved oxygen/organic enrichment (2010)
Shasta River	Temperature, dissolved oxygen (2007)
Scott River	Temperature, sediment (2006)
Salmon River	Temperature (2005)
Trinity River	Sediment (2001)

Source: EPA, 2008

1.5.3 Past or Existing Restoration Efforts

Numerous programs have been established in an effort to restore natural function of the Klamath River, to the extent possible, and to encourage recovery of the basin's ESA listed species. This section highlights some of these activities; however, it does not attempt to identify all past and present planning activities.

The Klamath River Basin Fishery Resources Restoration Act of 1986 established the Klamath Fishery Management Council to monitor the fish population and recommend annual fish harvest limits, as well as the Klamath River Basin Fisheries Task Force to advise the Secretary of Interior regarding implementation of the Restoration Program (U.S. Government Accountability Office, 2005). A USFWS office was established in Yreka, CA in 1987 to facilitate implementation and management of the Restoration Program (U.S. Government Accountability Office, 2005). However, due to funding constraints the Restoration Program was left to expire in 2006.

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 required the NMFS to develop a recovery plan for SONCC ESU coho salmon in 2007 (NOAA, 2011). Since the early 1990s, harvesting of the Klamath River fall-run Chinook salmon stock was restricted offshore from California and Oregon due to low returns. However, based on recent increases in naturally spawning adults, the Secretary of the Interior declared Klamath River fall Chinook salmon populations restored in 2011 (NOAA, 2011).

Additional restoration and recovery actions include construction and monitoring of off-channel ponds (initiated in 2010) to address limited winter rearing habitat for ESA-listed coho salmon. Monitoring efforts following construction showed more than 250 juvenile coho salmon moving into the new ponds in Terwer Creek, illustrating the importance of this habitat for overwintering coho salmon. In 2010 NOAA's Open Rivers Initiative provided funding to the Shasta River Fish Passage Project for removal of the Grenada Irrigation District diversion dam. The Nature Conservancy continues to work on the Shasta River Big Springs Creek to restore more than 11 miles of salmon and steelhead spawning and rearing habitat.

The Trinity River Flow Evaluation (USFWS and Hoopa Valley Tribe, 1999) recommended a restoration strategy for the Trinity River that integrates restoration of riverine processes with the instream flow-dependent needs of salmonids. As a result, the Trinity River Restoration Program strives to restore the natural physical processes in the river and create spawning and rearing conditions (including adequate water temperatures) downstream of the dams that best compensate for lost habitat upstream (Trinity River Restoration Program, 2009).

The federal Wetlands Reserve Program is one of several programs implemented by the U.S. Department of Agriculture. Since the program's inception in 1990, it has resulted in the restoration of approximately 30,400 acres of wetlands in Oregon's Upper Klamath River Basin (Duffy et al., 2011).

Some major Reclamation actions to conserve native fish include construction of a fish screen on the A-Canal, completed in 2003; completion of the Link River Dam fish ladder in 2005; numerous monitoring and research studies; and the removal of Chiloquin Dam on the Sprague River to allow suckers access to historic spawning areas in 2008. The USFWS maintains a habitat restoration program and activities on the NWRs, including walking wetlands. The Nature Conservancy restored 7,000 acres of wetlands at the Williams River Delta of Upper Klamath Lake.

1.5.3.1 Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement

A large coordinated Klamath Basin restoration planning effort involving 42 Klamath Basin stakeholders began in 2007 and was completed in 2010. The resulting agreement, the KBRA, takes a multi-dimensional approach that attempts to resolve complex problems by focusing on species recovery while recognizing the interdependence of environmental and economic problems in the Basin's rural communities (Klamath Settlement Group, 2009a). The goals of the KBRA include:

- Restoring and sustaining natural production and providing for full participation in ocean and river harvest opportunities of fish species throughout the Klamath Basin

- Establishing reliable water and power supplies which sustain agricultural uses, communities, and NWRs

- Contributing to the public welfare and the sustainability of all Klamath Basin communities

The KBRA was intended to be implemented alongside the Klamath Hydroelectric Settlement Agreement (KHSA), which lays out the process for conducting necessary additional studies, environmental reviews, and a decision by the Secretary of the Interior (called Secretarial Determination) surrounding the possible removal of the lower four dams on the Klamath River owned by PacifiCorp beginning in 2020. These dams are Iron Gate, COPCO 1, COPCO 2, and J.C. Boyle. The KHSA includes provisions for the interim operation of the dams prior to dam removal, the process to transfer, decommission, and remove the dams, and the transfer of Keno Dam to the Department of the Interior (Klamath Settlement Group, 2009b). On December 31, 2015 the KBRA terminated because federal authorizing legislation was not enacted. The KHSA is still in effect but its interdependent connection to the KBRA requires its amendment to continue. On February 2, 2016 an agreement-in-principle to amend the KHSA was announced between the states of Oregon and California, PacifiCorp, and the US Departments of Interior and Commerce. The ultimate timing of its implementation is not currently known, but the KHSA describes the implementation of the dam removal action in 2020.

A joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) analysis has been performed and a final Environmental Impact Statement/Environmental Impact Report containing 18 alternatives has been completed. Five of the alternatives, including the no project/no action alternative, were carried forward for detailed evaluation. Among the five alternatives carried forward is full implementation of the KHSA and KBRA (Interior and the California Department of Fish and Game, 2011; Thorsteinson et al., 2011).

1.5.4 Future Challenges

The primary challenge of the Klamath River Basin Study is determining how to address the uncertainties related to water management in the basin. For example, the fate of the KBRA and KHSA is unknown at this time. Quantification of potential imbalances in current and projected future supply and demand and subsequent evaluation of identified management strategies would yield vastly different outcomes, depending on whether the four lower Klamath River dams are removed and associated restoration efforts move forward. To address this future challenge, the Klamath River Basin Study takes a scenario approach in order to increase flexibility in evaluating climate change impacts on the baseline system.

1.6 Collaboration and Outreach

The Klamath River Basin Study is a collaborative effort involving Reclamation and two non-federal cost share partners, the CDWR and the OWRD. The study seeks additional tribal and stakeholder involvement through a process described in the Public Participation and Outreach Plan. The Public Participation and Outreach Plan describes the tribal, stakeholder, and public participation process; however, an overview is provided in this chapter. The process of involving tribes and stakeholders is likely to evolve: consequently the plan will be adapted, as needed, as the study gets underway.

The Klamath River Basin Study was guided by a technical working group (TWG), with input from interested organizations and individuals. The non-federal cost share partners (CDWR, OWRD, and Reclamation) comprise the TWG, which was the primary decision making body for the Basin Study and which conducted a peer review of technical deliverables. Interested organizations and individuals were asked to provide input on the study approach and findings throughout the process. These groups or individuals included federal, state, and local governments; tribes; water use organizations; and non-profit groups. The general public was kept apprised of the progress and findings of the Basin Study primarily through existing public meetings that took place across the region. Figure 1-3 illustrates the Basin Study organization.

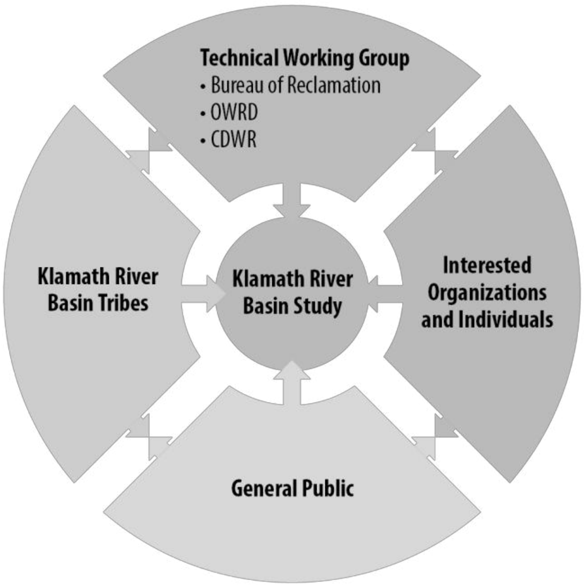

Figure 1-3. Klamath River Basin Study organizational chart

1.7 What to Expect in this Study

The Klamath River Basin Study, consistent with the Basin Study Framework (Reclamation, 2009), contains four primary components. These are listed in Section 1.2, Purpose, Scope, and Objectives of the Study. They are also illustrated in Figure 1-4, which provides an overview of the basin study approach, highlighting Chapter 1. The first component of the Klamath River Basin Study includes an assessment of current and projected future water supplies. Projected scenarios of future water supply are drawn from methods described by WWCRA (Reclamation, 2011d). However, this study also incorporates climate scenarios from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Taylor et al., 2012). The Klamath River Basin Study also utilizes streamflow reconstructions from tree-rings to provide a greater variability context for historical climate and hydrologic conditions. This portion of the study evaluates past and projected future changes in precipitation and temperature, as well as changes in snowpack, evapotranspiration, and groundwater if possible.

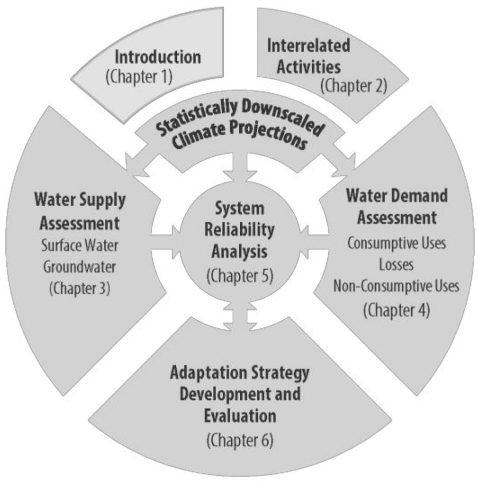

Figure 1-4. Overall approach for Klamath River Basin Study, highlighting Chapter 1

The second component of the Klamath River Basin Study includes an assessment of current and projected future water demands. The assessment includes quantification of historical and projected future agricultural demands and open water evaporation. This study takes advantage of newly available demand information through the WWCRA.

The third component of the Klamath River Basin Study includes evaluating the watershed's ability to meet or withstand any identified future water supply/demand imbalances (these may include infrastructure, fish and wildlife, etc.). System reliability is determined by testing the system against various defined performance measures. These measures were developed with input from the Klamath River Basin Study TWG and interested organizations and individuals. This component relies heavily on projections from the first two components of the study (assessment of current and projected future water supply and demand). The proposed approach includes evaluation of risk and reliability considering multiple scenarios of projected future climate/demand conditions.

The fourth and final component of the Klamath River Basin Study includes identifying and quantifying potential adaptation strategies or opportunities to address potential supply/demand imbalances, considering a range of future scenarios. Adaptation strategies include a range of concepts including operational changes or habitat restoration, among others. In general, the study aimed to identify potential adaptation strategies that that have the potential for reducing water supply/demand imbalances that are likely as a result of climate change.

Adaptation strategies are evaluated using a decision-making framework. Chosen strategies in the Klamath River Basin Study were general in nature in order to evaluate the sensitivity of the basin's water resources to different types of strategies.

The goal for the Klamath River Basin Study is to provide added value to past and ongoing studies to work toward meeting the needs of water users and fish and wildlife in the basin. Further, the Basin Study provides a holistic view of the entire Klamath watershed and does not discount any recommended adaptation strategies. All adaptation strategies identified through the stakeholder and public participation process are included as Appendix E to the Klamath River Basin Study final report.

1.8 Supporting Information

The literature synthesis, along with a list of corresponding references, is provided as Appendix A.

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Chapter 2
Klamath River Basin Study
Identification of Interrelated Activities

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Contents

Figures

Chapter 2
Identification of Interrelated Activities

The Klamath River Basin is unique in that its natural setting and inherent challenges require cooperation among all levels of government and organization. The Klamath River Basin is an interstate watershed with six federally recognized tribes. Three ESA listed fish species are directly affected by water use, and these are being managed by a combination of federal, state, and local efforts. The variety of groups with management responsibilities in the basin has resulted in numerous interrelated activities and coordinated efforts. Following is a brief description of interrelated activities in the Klamath River Basin that are relevant to the Klamath River Basin Study. Also, Figure 2-1 illustrates how Chapter 2 fits into the overall basin study approach.

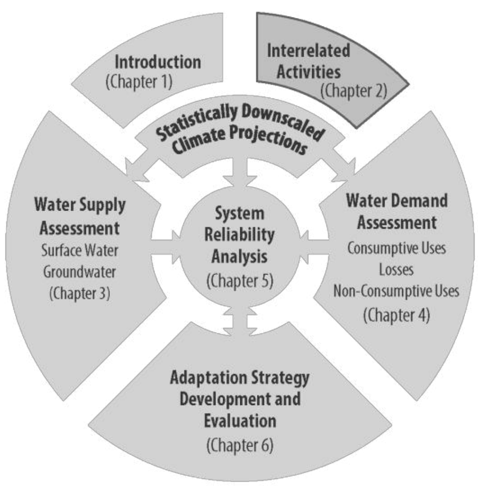

Figure 2-1. Overall approach for Klamath River Basin Study, highlighting Chapter 2

2.1 Federal

Because the Klamath River Basin contains two federal irrigation projects (Reclamation's Klamath Project and a part of the Trinity River Division), provides habitat for species listed as threatened or endangered under ESA, contains one national park (Crater Lake National Park) and thousands of acres of National Forest and Bureau of Land Management Lands, plus is home to six federally recognized native tribes, numerous past and ongoing federal activities overlap and have common goals. The primary common thread that brings various agencies and activities together is the effort to recover three of the basin's seven ESA listed fish species: the SONCC ESU coho salmon (threatened) and Lost River and shortnose suckers (endangered).

Reclamation's Klamath Project first began providing water to irrigators in 1907, and since then the project has grown to about 254,000 acres of land. The Upper Klamath Basin hydrologic system was significantly altered as a result of:

- wetlands drained from Upper and Lower Klamath and Tule Lakes
- construction of dams and conveyance structures by Reclamation
- construction of seven hydroelectric facilities by PacifiCorp
- a Bureau of Indian Affairs dam on the Sprague River, subsequently removed by Reclamation in 2008
- other water diversions and withdrawals above the Klamath Project

Development in the Klamath River Basin over the last century, including construction of dams without fish passage facilities, has caused declines in anadromous and resident fish species. Their decline was recognized in the early 1980s with passage of the Klamath River Basin Fishery Resources Restoration Act (P.L 99-552), which established the Klamath Basin Restoration Fisheries Task Force and charged it with developing a 20-year Klamath River Basin Conservation Area Fishery Restoration Program. This program was allowed to expire in 2006 and no longer operates; however, numerous restoration projects were implemented over the 20-year period.

Since the listing of three Klamath River Basin fish species under ESA, Reclamation has worked with the NMFS (responsible for SONCC ESU coho salmon) and the USFWS (responsible for Lost River and shortnose sucker) on Klamath Project operations plans that reduce regulated flow impacts to these species (Reclamation, 2011f; Reclamation, 2012a). Due to low water availability in 2001, Reclamation was not able to meet irrigation needs or recommended Klamath River flows and Upper Klamath Lake levels for the ESA listed species. As a result, the National Research Council (charged with advising the federal government on science issues) was directed to review the science underlying

recommendations by the NMFS and the USFWS (National Research Council, 2002; National Research Council, 2004; National Research Council, 2008).

In an interim report completed in 2002, the National Research Council concluded that the recommendations had substantial scientific support except for those regarding minimum lake levels of Upper Klamath Lake and increased minimum flows in the mainstem Klamath River. Also, it found Reclamation's Klamath Project operations would not affect tributary conditions, which were deemed the most critical for species survival. At the same time, the National Research Council found Reclamation's proposed minimum Klamath River flows would result in an unknown risk to the population.

In their final report in 2004, the National Research Council corroborated their interim findings and, in addition, provided a broad set of recommendations for the recovery of threatened and endangered species in the entire basin, including expanding the scope of ESA actions by the NMFS and USFWS, planning and organizing research activities and monitoring, identifying specific high priority recovery actions for endangered suckers (e.g., removal of Chiloquin Dam which occurred in 2008), identifying information needs related to SONNC ESU coho salmon, and identifying remediation measures that could be implemented based on current information.

Reclamation has conducted numerous studies with the overarching goal of reducing the Klamath Project impacts on the natural river system. These studies include efforts to evaluate potential new off-stream storage facilities, groundwater pumping and aquifer storage options, and water banking mechanisms. Examples of these studies include the Long Lake Valley appraisal report (Reclamation, 2011a), the Upper Klamath Basin Offstream Storage Investigations, Initial Alternatives Information Report (Reclamation, 2011e), the Klamath Project Yield and Water Quality Improvement Options Appraisal Study (Reclamation, 2012e), and the KBRA On-Project Plan (Klamath Water and Power Agency, 2011).

Other federal agencies have also undertaken numerous activities with the goal of managing natural resources for the livelihoods of Klamath River Basin residents while maintaining, as much as possible, the natural ecosystem critical for ESA listed species and others. The Bureau of Land Management (BLM) has conducted watershed analyses for the mainstem Trinity River (BLM, 1990), for which the goal was to compile existing knowledge about various physical processes important in the basin and work toward more holistic ecosystem management. The BLM was also involved in the process to classify reaches of the Klamath River and its tributaries in the National Wild and Scenic Rivers System (BLM, 1990).

The U.S. Forest Service (USFS) conducted a watershed analysis for the Six Rivers National Forest (Orleans Ranger District) in 2003 to support potential watershed restoration actions related to the recovery of ESA listed anadromous salmonid fish species, and to implement fuels reduction around local

communities, municipal water sources, and private lands as outlined by USFS fire plans (USFS, 2003). The Six Rivers National Forest intersects part of the Lower Klamath Basin. The USFS also completed a land and resource management plan (USFS, 1995) for the Six Rivers National Forest, which takes into account impacts to the ESA listed species.

The USFWS and NMFS work cooperatively with private entities to produce habitat conservation plans for incidental take of fish and wildlife species. The USFWS has also been involved in Trinity River Restoration Program efforts to improve the natural function of the Trinity River below Lewiston Dam. For example, they completed the Environmental Impact Statement/Environmental Impact Report (EIS/EIR) (USFWS et al., 2000) on the Trinity River Flow Evaluation Study, which resulted in the December 19, 2000 Record of Decision to establish the Trinity River Restoration Program (Interior, 2000).

The NMFS has been involved in a wide variety of interagency efforts, including the development of the SONCC ESU coho salmon recovery plan and working with the North Coast Regional Water Quality Control Board to develop TMDLs for the Klamath River in California. The NMFS has also been involved in a number of habitat restoration projects including construction of off-channel ponds by the Mid-Klamath Watershed Council and Karuk Tribe, and installation of a series of boulder step pools to replace gravel push-up dams in a partnership between Scott Valley Resource Conservation District and local landowners (NMFS, 2009; NMFS, 2011).

The KBRA and KHSA are companion agreements between federal agencies, Klamath Basin Tribes, irrigators, fishermen, conservation groups, counties, the states of Oregon and California, and dam owners, which aim to restore Klamath River Basin fisheries and sustain local economies. The agreements include:

- removal of four dams in the upper Klamath River
- increased flows for fish
- greater reliability of irrigation water deliveries
- reintroduction of salmon above the dams and into and above Upper Klamath Lake
- investment in comprehensive and coordinated habitat restoration
- a power program for Klamath River Basin farmers and ranchers
- mitigation to counties for the effects of dam removal
- investment in tribal economic revitalization

Current Federal Energy Regulatory Commission (FERC) licenses for the dams expired in 2006. These facilities are now operated on annual licenses using existing operating plans. FERC continues to participate in the ongoing process to determine the fate of the dams.

2.2 Tribal

Tribal activities in the watershed include the Klamath Basin Tribal Water Quality Work Group, which conducts coordinated surface water sampling activities and participates in the Klamath River Basin monitoring program. The Klamath Basin Monitoring Program is a multi-agency organization aiming to implement, coordinate, and collaborate on water quality monitoring and research throughout the Klamath Basin. As an example, Reclamation and the Klamath Tribes have together been collecting water quality data in Upper Klamath and Agency Lakes since 1988.

The Karuk Tribe and the USFS have coordinated on the land management of the Katimiin Cultural Management Area near Somes Bar, California. Management strategies outlined are consistent with both Karuk cultural environmental management practices and the Klamath National Forest Land and Resource Management Plan. The Katimiin Cultural Management Area is where the Tribe's Pikyawish, or World Renewal, ceremonies are concluded each year (CDWR, 2013).

Three of the six federally recognized tribes in the Klamath River Basin have supported the KBRA and KHSA agreements (Klamath Settlement Group Communications Committee, 2009a, b). Although the others also strive for ESA listed species recovery and return of the Klamath River to a more natural condition, some have expressed the position that dam removal would occur more immediately if left to the FERC relicensing process.

The Hoopa Valley Tribe worked alongside Interior to lead the Trinity River Restoration Agreement, which aims to mitigate the detrimental effects of decades of out of basin diversions of Trinity River water to Reclamation's Central Valley Project (USFWS et al., 2000). The Hoopa Valley Tribe worked with the USFWS to complete the Trinity River Flow Evaluation Study, which became the basis for the Trinity River Restoration Agreement (USFWS and Hoopa Valley Tribe, 1999). The Yurok Tribe is also a member of the council governing the Trinity Restoration Agreement.

The tribes in the Klamath River Basin have also conducted or commissioned their own studies to quantify the needs of environmental resources on which they depend. For example, Trihey and Associates, Inc. (1996) sought to quantify the monthly flow requirements of Tribal Trust fish species in the mainstem Klamath River between Iron Gate Dam and the river mouth.

2.3 Interstate (including regional)

California and Oregon have coordinated on several activities involving the Klamath River, which flows between the states. The Klamath River Basin Compact was ratified by the states of Oregon and California in April 1957. The compact was meant to facilitate and promote the orderly, integrated, and comprehensive development, use, conservation, and control of Klamath River water for various purposes. Uses include domestic, irrigation, protection, and enhancement of fish and wildlife, industrial, hydroelectric power production, navigation, and flood prevention.

In addition to water quantity and timing, California and Oregon have coordinated on water quality issues with respect to the development of TMDLs for the mainstem Klamath River and its tributaries. The California North Coast Water Quality Control Board and the Oregon Department of Environmental Quality coordinated on completion of draft TMDLs for respective parts of the mainstem river by 2010. These are both complete and await approval.

PacifiCorps's hydropower facilities in the Klamath River Basin reside in both California and Oregon. As such, California and Oregon have undertaken studies to evaluate effects of these facilities on the environment, as well as potential effects of removal of the dams. For example, the California Coastal Conservancy (2006) evaluated sediment supplies under potential dam decommissioning scenarios.

2.4 State

The Klamath River Basin spans parts of California and Oregon and both states have been involved in management and planning efforts in the basin. In California, the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) aims to act as a nexus between statewide planning efforts and local planning, helping to synchronize the large, complex planning processes, regulations, and priorities at the state level with the locally specific issues, data, concerns, planning, and implementation needs at the local level.

The OWRD and CDFW (which prior to January 2013 was the California Department of Fish and Game) have collaborated with federal agencies and tribes on a number of studies. For example, the Instream Flow Study Phase II (Hardy et al., 2006) for the Klamath River, which was developed to help determine flow needs of ESA listed fish species, was a collaborative effort involving Utah State University, the USFWS, the NMFS, the USGS, the Bureau of Indian Affairs, Reclamation, CDFG, OWRD, the Karuk Tribe, the Hoopa Tribe, and the Yurok Tribe. In another example, the USGS and OWRD collaborated in a study to characterize regional groundwater in the Upper Klamath Basin and develop a groundwater flow model to test management options (Gannett et al., 2007).

2.4.1 Relationship to State Law including State Water Plan

Water rights adjudications in California and Oregon are in different stages of completion. The Shasta Valley in California was adjudicated in 1932, the Scott Valley in California in 1980. The mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court demarking a significant milestone in determining the water rights of the Upper Klamath Basin. The adjudication covers all claims to the use of surface water that predate Oregon's 1909 Water Code. It also covers those referred to as "federal reserved water right" claims. The Circuit will now handle the remaining administrative process prior to issuance of a Court Decree. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the "time immemorial", which may significantly affect water management in the Upper Klamath Basin. The Klamath Tribes have currently agreed not to exercise their rights prior to August 9, 1908. Another significant finding of the Final Order of Determination granted co-ownership of Klamath Project water rights to both Reclamation and Klamath Project water users.

California's water plan update (CDWR, 2013) includes a discussion of activities through the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) as well as a discussion of overall planning activities in the Klamath River Basin. However, most planning activities are carried out by federal agencies and coordinated groups.

Oregon completed its water resources strategy in 2012 and the state legislature has directed that this plan be updated every 5 years (OWRD, 2012). The plan discusses general recommendations for additional groundwater investigations, improved water monitoring, and continued research on the implications of climate change. Like California, Oregon does not direct planning activities in the Klamath River Basin as these are primarily carried out by interagency consortia.

2.5 Local

There are numerous local landowner and water user groups within the Klamath River Basin and many of these interact with interagency planning efforts. One example is the KBRA/KHSA planning process, which involves 42 stakeholder groups including local water managers and land owners. Also, the Klamath Basin Rangeland Trust, a nonprofit organization with the mission of improving water availability in the Upper Klamath Basin, was formed in 2002. The Trust facilitates partnerships between private landowners and public agencies to conserve water resources and restore habitat and wetlands.

Local groups are also involved in the Trinity River Restoration Planning efforts, as many of the restoration projects take place using local resources and expertise. For example, the Coordinated Resource Management Plan Group for the South

Fork Trinity River is a consortium of local landowners and various agencies who are interested in water conservation, habitat improvement, and educational outreach in the South Fork Trinity River. The group is funded by the Trinity River Restoration Program. Also, in coordination with the NMFS, Scott Valley Resource Conservation District and local landowners installed a series of boulder step pools to replace gravel push-up dams in the basin.

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Chapter 3
Klamath River Basin Study
Assessment of Current and Future Water Supply

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Chapter 3 Assessment of Current and Future Water Supply

3.1 Introduction

The purpose of the Klamath River Basin Study is to identify current and projected imbalances in water supply and demand across the entire Klamath River Basin, and to develop and analyze adaptation strategies to help resolve any identified imbalances. A system diagram illustrating the primary components of the Klamath River Basin Study is provided in Figure 3-1.

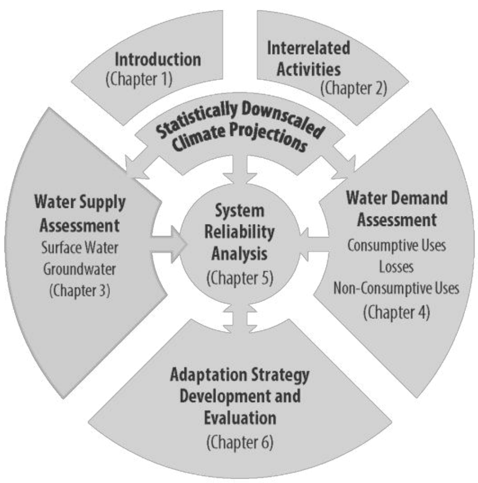


Figure 3-1. Overall approach for Klamath River Basin Study, highlighting Chapter 3

The water supply assessment consists of analyses of both surface and groundwater resources, including quantification of historical trends and projections for two future planning horizons, the 2030s (represented as the mean from 2020–2049) and 2070s (represented as the mean from 2060–2089). The water demand assessment (Chapter 4 of the Klamath River Basin Study) consists of analysis of agricultural, tribal/cultural, environmental, evaporative demands, and domestic, municipal, and industrial demands. Statistically downscaled

climate projections provide the basis for the assessments of projected water supply and demand. They are also used directly, along with supply and demand information, to evaluate the river system with respect to environmental demands such as water quality. Current and projected water supply and demand are brought together to evaluate how the river system has responded historically to changes in supply and demand, and may respond in the future as a result of climate change. Potential water supply/demand gaps are evaluated as part of a system reliability analysis. Performance measures are used to analyze system reliability; these are developed through an input process involving Klamath River Basin Study cost share partners, stakeholders, and tribes. The analysis of system risk and reliability is summarized in Chapter 5.

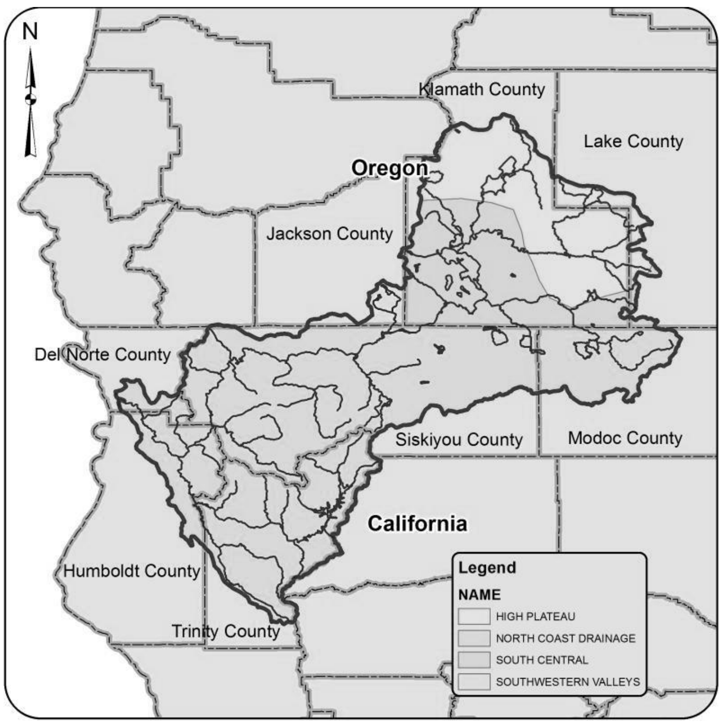
This chapter summarizes the findings of the current and future water supply assessment. The chapter begins with a general discussion of surface and groundwater resources in the watershed, followed by discussions of the technical approach for evaluation of historical water supply (surface and groundwater) and an assessment of historical water supply. The chapter then assesses projected water supply (surface and groundwater), including a detailed discussion of the approach for developing climate scenarios. The assessment of historical and projected surface water supply encompasses the entire Klamath River watershed, while the assessment of historical and projected groundwater supply is focused on three dominant groundwater basins in the watershed: the Upper Klamath Basin, Shasta Valley, and Scott Valley. The difference in approach is due to the extents of existing surface and groundwater modeling tools that may be applied in the study.

3.2 Description of Surface and Groundwater Supplies

This section briefly describes the general characteristics of surface and groundwater in the Klamath River Basin. These characteristics provide context for subsequent analysis of historical and projected water supply throughout the watershed. As previously mentioned, surface water supply is analyzed basin-wide, concentrated on three primary regions for analysis of groundwater supply: the Upper Klamath groundwater basin, the Scott Valley groundwater basin, and the Shasta Valley groundwater basin.

The Klamath River Basin is a complex watershed, due in part to its distinct climatic regions and distinct geologic zones which influence surface and groundwater interactions throughout the watershed. The Klamath River Basin spans four NOAA climate divisions, including High Plateau, North Coast Drainage, South Central, and Southwestern Valleys (Figure 3-2). Climate divisions are generally climatically distinct regions; however, they are also defined by political boundaries, as evidenced on Figure 3-2 where climate divisions are separated by the Oregon-California border and, in one case, by county boundaries (the boundary between Southwestern Valley and South Central).

The elevation ranges of Klamath River Basin climate divisions help to illustrate the complexity of the watershed. Basin-wide elevations range from sea level to about 13,600 feet. These two elevation extremes both fall within the North Coast Drainage climate division. The High Plateau ranges between 4,200 feet and 8,500 feet, while the South Central region ranges between 2,870 feet and 8,000 feet. Even the Southwestern Valley Climate Division, which covers only 15 percent of the watershed, ranges between 3,000 feet and 9,040 feet.



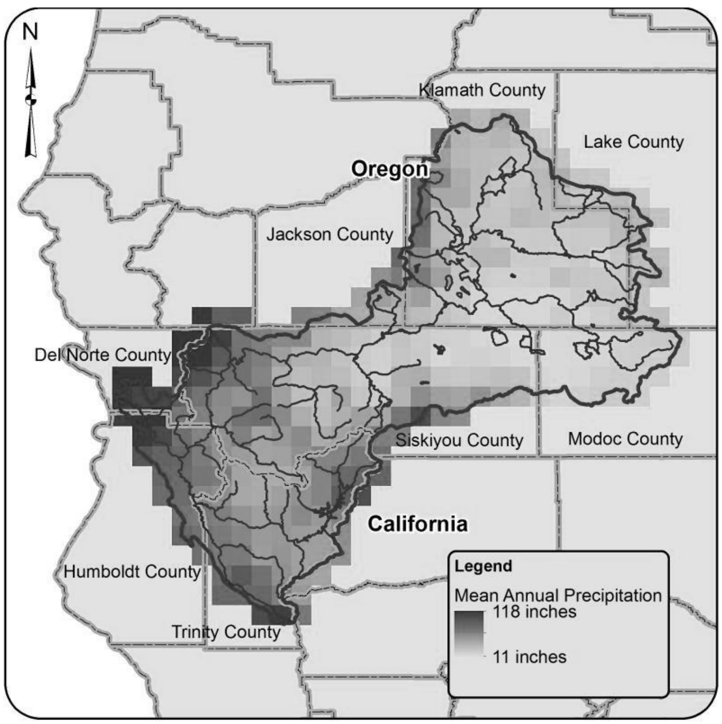
Source: NOAA, http://www.esrl.noaa.gov/psd/data/usclimdivs/boundaries.html.

Figure 3-2. Map of climate divisions within the Klamath River Basin

Mean annual precipitation and temperature were computed for the three dominant climate divisions within the watershed over calendar years 1950–1999, based on a widely used grid-based meteorological dataset developed by Maurer et al. (2002). This historical meteorological dataset is used as the basis for the historical and projected water supply assessments, as discussed later in this chapter.

Mean annual precipitation varies substantially across the three dominant climate divisions within the watershed (Figure 3-3), from about 24 inches per year in the

South Central to about 44 inches per year in the North Coast Drainage and about 26 inches in the High Plateau. The historical basin-wide mean annual precipitation over the same period is approximately 37 inches per year. Mean annual average temperature varies from almost 41 degrees Fahrenheit (F) in the High Plateau to 43 degrees F in the South Central and about 46 degrees F in the North Coast Drainage climate division, with a basin-wide average of 45 degrees F (computed over the same 1950–1999 period as for precipitation).



Source: based on meteorological data from Maurier et al., 2002

Figure 3-3. Mean annual precipitation (inches/year) over the period 1950–1999

The seasonality of precipitation and temperature in the Klamath River Basin is typical of coastal watersheds, where the winter season (defined as December through February) experiences the greatest precipitation, about 18 inches per year for this watershed historically (1950–1999), ranging from about 10 inches per year in the South Central to about 11 inches in the High Plateau and 22 inches in the North Coast Drainage. The summer season (defined as June through August) experiences relatively dry conditions, receiving about 2 inches per year for the same period with less than 12 percent of that experienced in the winter, and

ranging from slightly less precipitation in the North Coast Drainage to slightly more in the High Plateau.

Winter temperatures average about 31 degrees F over the historical period 1950–1999 across the basin and range from about 29 degrees F in the High Plateau and South Central to about 33 degrees F in the North Coast Drainage. Summer temperatures average about 60 degrees F basin-wide and range from about 58 degrees F in the High Plateau to about 60 degrees F in the South Central and about 61 degrees F in the North Coast Drainage. Note that diurnal fluctuations in temperature as well as temperatures at different elevations may vary substantially from these daily averages.

Table 3-1. Summary of Klamath River Basin characteristics

	Basin Wide	North Coast Drainage	South Central	High Plateau
Mean annual precipitation	37 inches	44 inches	24 inches	26 inches
Mean winter precipitation	18 inches	22 inches	10 inches	11 inches
Mean summer precipitation	2.1 inches	1.9 inches	2.1 inches	2.4 inches
Mean annual daily average temperature	45 degrees F	46 degrees F	43 degrees F	41 degrees F
Mean winter daily average temperature	31 degrees F	33 degrees F	29 degrees F	29 degrees F
Mean summer daily average temperature	60 degrees F	61 degrees F	60 degrees F	58 degrees F
Runoff ratio	0.46	0.52	0.27	0.24
Elevation range	0–13,600 feet	0–13,600 feet	2,870–8,000 feet	4,200– 8,500 feet

3.2.1 Surface Water

The Klamath River Basin may be considered a mixed rain and snow influenced watershed. March has historically had the greatest snowpack, averaging about 4.5 inches across the basin (statistics based on historical hydrologic model results are discussed below).

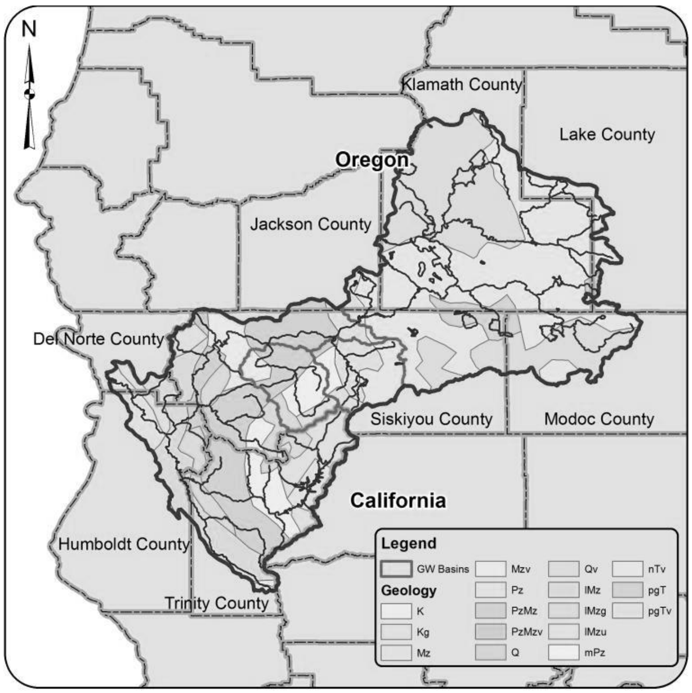
As previously mentioned, the relative magnitudes of key elements of the water balance in the Klamath River Basin vary due to its climatic diversity. Precipitation is one key element of the water balance described above. Other key elements include runoff and evapotranspiration. The ratio of mean annual runoff to mean annual precipitation is an indicator of how much precipitation results in streamflow as opposed to being lost through evapotranspiration or to groundwater recharge. On the whole, the basin has a historical runoff ratio of about 0.46, which translates to 46 percent or almost half of annual precipitation resulting in streamflow. This ratio varies substantially by climate division, from about 0.24 in the High Plateau climate division to about 0.27 in the South Central climate division and 0.52 in the North Coast climate division. In the High Plateau and South Central climate division areas evapotranspiration rates are higher, resulting in lower runoff ratios. In general, over snowmelt-dominated basins of the western

U.S., runoff ratios are typically close to 0.5. Little is known regarding how runoff ratios may change in a changing climate; however, future research may shed light on this question.

3.2.2 Groundwater

Groundwater systems are dynamic, with rates of recharge and discharge and hydraulic head varying in response to external stresses. Climate is one primary external influence on groundwater systems, along with human-caused stresses such as pumping, artificial recharge from canal leakage, and other sources. This section offers an overview of three primary groundwater basins to provide context for analysis of historical and projected future conditions in these areas and to provide greater understanding of how climate and other stressors may influence them.

The Klamath River Basin spans numerous geologic formations including volcanic, sedimentary, and granitic (Figure 3-4 and Table 3-2). Each formation, with its various overlying soil types, causes unique surface and groundwater interactions. Groundwater is an important water source for fish, wildlife, irrigators, and residents throughout the watershed, and in particular the Upper Klamath Basin and Scott and Shasta Valleys. For example, it provides cool, late summer streamflows to sustain fish at a critical time for spawning and rearing. In another example, some irrigators depend on groundwater supply to supplement surface water supplies during low water years where surface water supplies may not fully meet water needs, while many more irrigators depend solely on groundwater supplies. Increasing reliance on groundwater makes this an important component of the water supply assessment.



Source: Generalized Geologic Map of the United States, http://pubs.usgs.gov/atlas/geologic/

Figure 3-4. Map of geologic units within the Klamath River Basin

Table 3-2. Descriptions of Klamath River Basin geologic types by ID as represented in Figure 3-4

ID	Geology	ID	Geology
nTv	Neogene volcanic rocks	IMzu	Lower Mesozoic ultramafic rocks
Qv	Quaternary volcanic rocks	mPz	Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks
Mz	Mesozoic sedimentary rocks	IMzg	Lower Mesozoic granitic rocks
pgTv	Paleogene volcanic rocks	mPz	Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks
pgT	Paleogene sedimentary rocks	Pz	Paleozoic sedimentary rocks
PzMzv	Paleozoic and Mesozoic volcanic rocks	IMzg	Lower Mesozoic granitic rocks
IMz	Lower Mesozoic (Triassic and Jurassic) sedimentary rocks	Kg	Cretaceous granitic rocks
PzMz	Paleozoic and Mesozoc sedimentary rocks	K	Cretaceous sedimentary rocks
Mzv	Mesozoic volcanic rocks	Q	Quaternary deposits

As noted previously, the Klamath River Basin Study water supply assessment focuses on three primary groundwater basins including the Upper Klamath Basin, the Scott River Valley (Scott Valley), and the Shasta River Valley (Shasta Valley). The Upper Klamath Basin includes agricultural areas upstream of Upper Klamath Lake and areas in and surrounding Reclamation's Klamath Project, as well as Butte Valley and the Lost River drainage. Each of the three dominant groundwater basins is described below and highlighted in Figure 3-4.

3.2.2.1 Upper Klamath Groundwater Basin

The Upper Klamath groundwater basin spans about 8,000 square miles upstream of Iron Gate Dam on the Klamath River. Gannett et al. (2012) estimated approximately 500,000 acres of irrigated land for agriculture in 2011. Descriptions of the Upper Klamath groundwater basin primarily come from studies by Gannett et al. (2007) and Gannett et al. (2012).

The Klamath River Basin spans the Cascade Range geologic province (roughly corresponding with the Lower Klamath Basin) and Basin and Range geologic province (roughly corresponding with the Upper Klamath Basin). The Western Cascades sub-province of the Cascade Range constitutes part of the western boundary of the regional groundwater flow system and has very low permeability. The High Cascade sub-province of the Cascade Range consists mostly of volcanic vents and lava flows. There are two main areas in the Upper Klamath Basin with these Quaternary volcanic deposits: near Crater Lake (forming part of the northwest Upper Klamath Basin boundary), and from Mount Shasta east to Medicine Lake Volcano (forming part of the southern Upper Klamath Basin boundary).

Groundwater recharge from precipitation accounts for about 20 percent of the total precipitation in the Upper Klamath Basin. The exact percentage varies spatially and temporally (Gannett et al., 2007). The primary recharge areas in the upper Klamath Basin are the Cascade Range and uplands within and on the eastern margin of the basin. In the northeast part of the Upper Klamath Basin, basalt formations are an important source of recharge due to their high permeability. According to multiple references, at least 60 percent of the inflow into Upper Klamath Lake can be attributed to ground-water discharge in the Wood River sub-basin and springs in the lower Sprague River drainage and the Williamson River drainage below Kirk (Gannett et al., 2007).

Basin and Range Province deposits in the study area include a region from Clear Lake Reservoir eastward to the Upper Klamath Basin boundary. This region generally has low permeability. The region around the Tule Lake sub-basin and to the south consists of major water-bearing volcanic rock from the Late Miocene to Pliocene eras. Rock from these periods consists of volcanic vent deposits and flow rocks. These are generally located throughout the area east of Upper Klamath Lake and Lower Klamath Lake, underlying most of the valley-fill and basin-fill deposits in the study area. The lake deposits near the original lakebeds have much lower groundwater yield due to low permeability and a tendency to

have confining layers. About a mile below J.C. Boyle Dam, a large spring complex contributes significant flow to the Klamath River, on the order of 200 cubic feet per second.

The City of Klamath Falls, which is the primary population center in the Upper Klamath Basin at about 21,000 residents, is entirely supported by groundwater sources. Demand for groundwater has increased in recent decades in the Upper Klamath Basin as a replacement water source for both municipal and agricultural uses.

3.2.2.2 Scott Valley Groundwater Basin

The Scott River is a major tributary of the Klamath River. The Scott Valley sub-basin consists of 813 square miles, approximately 63 percent in private land and 37 percent in federally managed lands (Harter and Hines, 2008). It is fed by a number of tributaries, many of which become dry in the summer months. CDWR Bulletin 118 (2003), which describes California's primary groundwater basins, characterizes the Scott Valley Groundwater Basin as a narrow alluvial floodplain about 28 miles long and ½ mile to 4 miles wide. The basin boundary is generally defined as the contact between the valley alluvium and rocks from the surrounding mountains, dating from Pre-Silurian to Cretaceous. The CDWR Bulletin 118 groundwater basin within the Scott Valley defines the model domain for the assessment of groundwater supply for this region.

The largest water storage in the watershed occurs in the alluvial fill of the Scott Valley groundwater basin, which is recharged annually by the Scott River and tributary streams, and by infiltration of precipitation and snow melt. This flood plain aquifer area was calculated to represent more than half of the total groundwater stored in the Scott Valley (Mack, 1958). The recent alluvium ranges in thickness from less than one foot to greater than 400 feet in the center of the Scott Valley at its widest point. The thickness of the alluvium decreases both to the north and to the south (Harter and Hines, 2008).

The Scott Valley's largest municipalities, Etna and Fort Jones, use a combination of surface and groundwater sources. Most rural residences use wells, but a few are served by springs and surface diversions (Harter and Hines, 2008). Land use is dominated by agriculture and cattle-raising. Almost 90 percent of the agricultural area within Scott Valley is used for alfalfa and pasture (CDWR, 2000). CDWR (2003) estimates that groundwater use for agriculture and municipal/industrial demand is about 1,300 acre-feet (AF), based on the 1991 flow augmentation survey for Scott Valley (CDWR, 1991).

3.2.2.3 Shasta Valley Groundwater Basin

The Shasta River is near the size of the Scott Valley and encompasses almost 800 square miles. The agricultural area within the Shasta Valley is comprised primarily of pasture and alfalfa, which amounts to about 80 percent of the total agricultural area. Many sub-basins of the Shasta Valley have pasture/hay and cultivated crops, which together account for more than 10 percent of the land area.

CDWR Bulletin 118 describes the Shasta Valley as having Quaternary alluvium as the primary formation supporting groundwater. This formation appears continuous throughout the valley region. Mack (1960) also reported volcanic rock formations of the western Cascade Mountains and the ancestral Mount Shasta debris avalanche. The southeastern boundary of the watershed is formed by Mount Shasta, one of the few glacier peaks in California. Glacial melting on Mount Shasta and mountain precipitation are principal sources of groundwater recharge in the Shasta Valley. A portion of this recharge reaches the Shasta River through spring discharge in the vicinity of Big Springs (CDWR, 1991). The CDWR Bulletin 118 groundwater basin within the Shasta Valley defines the model domain for the assessment of groundwater supply for this region.

The hydrology of the Shasta River has been and continues to be affected by Dwinnell Dam (built in 1928 and raised in 1955), surface water diversions, and interconnected alluvial groundwater pumping. Domestic, municipal, and industrial water use information available for the Shasta Valley, which had a population of 18,225 based on the 2000 Census, primarily consists of urban water management plans for the cities of Yreka and Weed, California. Water supply for the City of Yreka, with a population of 7,765 according to the 2010 Census, is completely sourced from surface water. The water supply for Weed, with a 2010 population of 2,967, is comprised of springs and wells.

3.3 Historical Surface Water Availability

This section summarizes historical and current surface water availability in the Klamath River Basin. Specifically, it provides a brief discussion of previous studies, a discussion of data and models used, and an analysis of historical availability and trends. Although the literature synthesis (Appendix A of the Klamath River Basin Study Report) contains a detailed discussion of previous studies, this section touches on those related to historical water supply availability to provide context for the assessment of surface water supplies.

3.3.1 Previous Studies

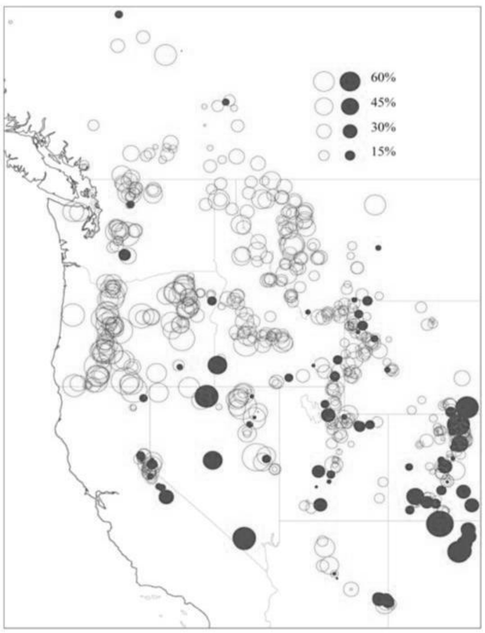
Numerous studies conducted over regions including northern California show increasing trends in historical temperatures, both annually and seasonally (Bonfils et al., 2007; Cayan et al., 2001; Dettinger and Cayan, 1995). Temperature increases over the 20th century have been estimated at 1.7 degrees F (1895–2011 over California by Moser et al., 2012) and 0.2–1.5 degrees F (difference between

1991–2007 and 1961–1990 over Shasta-Trinity National Forest by Furniss et al., 2012). Historical trends in precipitation have been inconsistent. Furniss et al. (2012) found no apparent increase in precipitation variability, but found an increase in winter, defined as January and February (0.1 to 7.9 inches) and growing season precipitation (0.1 to 2.1 inches). Research has shown small increasing trends in the frequency of historical extreme events over the mid-Pacific region (Kunkel, 2003; Madsen and Figdor, 2007; Gutowski et al., 2008).

Historical trends in snowpack and runoff over Northern California include declines in spring snowpack and earlier snowmelt runoff (Knowles et al., 2007; Regonda et al., 2005; Peterson et al., 2008; Stewart, 2009; Furniss et al., 2012; Reclamation, 2011c). However, glaciers on Mount Shasta are among the few in the world that are increasing in size (Furniss et al., 2012). Note that any trends in climate and water balance (i.e., snowpack and runoff) are dependent on the time period of analysis and are a direct result of the combined influences of natural climate variability and climate change (Reclamation, 2011k).

In the Upper Klamath River Basin, dry season (April to September) and summer streamflow (July to September) declined 16 percent and 38 percent, respectively during the period between 1961 and 2009 (Mayer and Naman, 2011). This decline is closely associated with decline in April 1 snowpack, which decreased approximately 40 percent during the same study period for snowcourse sites located below 1820 meters (5,970 feet) in elevation.

In response to temperature increases in the Pacific Northwest (Cayan et al., 2001; Regonda et al., 2005), snowpack in western North America has declined over the past 50 years (Mote et al., 2008). Figure 3-5 illustrates declines in April 1 snow water equivalent (SWE) at 594 locations in the western U.S. and Canada between 1950 and 2000. Mote et al. (2008) noted that the Pacific Northwest (generally including Washington, Oregon, and Idaho) has experienced the largest decline in snowpack in the western U.S. Although many regions have experienced decreasing trends, some regions have experienced increasing trends in April 1 SWE, namely in parts of the southwestern U.S.



Source: Mote et al., 2008
Note: Negative trends are shown by open red circles, positive trends by solid blue circles.

Figure 3-5. Relative trends in April 1 SWE at 594 locations in the western U.S. and Canada, 1950–2000

Attribution studies have aimed to distinguish historical trends due to climate change versus trends due to natural climate variability (Bonfils et al., 2007 and Cayan et al., 2001 for the western United States; Gershunov et al., 2009 for California and Nevada). Bonfils et al. (2008) found that increases in daily minimum and maximum temperatures over 1950–1999 cannot be fully explained by natural climate variability. Pierce et al. (2008) found that climate change may be the cause of about half of reductions in the fraction of annual precipitation falling as snow observed in the western United States from 1950 to 1999. The strongest changes in winter runoff, and in the fraction of precipitation accumulated as snow, have occurred at medium elevations (750–2,500 meters or 2,460–8,200 feet and 500–3,000 meters or 1,640–9,840 feet, respectively) close to freezing level. These are not likely to be associated with natural variability (Hidalgo et al., 2009). Barnett et al. (2008) found that, over the western United States, up to 60 percent of the climate-related trends in streamflow are human induced. These as well as other attribution studies of streamflow timing (Hidalgo et al., 2009 and Das et al., 2009) and snow/rain days (Das et al., 2009) show that statistical significance of the anthropogenic signal is greatest at the scale of the

western U.S. and weak or absent at the watershed scale, except in the Pacific Northwest (Hidalgo et al., 2009). However, attribution of any apparent trends in precipitation to climate change remains difficult (Hoerling et al., 2010).

3.3.2 Approach

The general approach for assessing historical surface water supply in the Klamath River Basin is to evaluate how historical climate has influenced the quantity, timing, and form of precipitation falling on the landscape. Assessment of historical water supply involves (1) evaluating trends in historical climate using a widely used spatially distributed meteorological dataset; (2) utilizing a hydrologic model to simulate the partitioning of precipitation into snow storage, evapotranspiration, runoff, and recharge to groundwater based on meteorological inputs and landscape characteristics; and (3) evaluating trends in historical water balance parameters based on hydrologic model simulations. This overall approach is illustrated by Figure 3-6.

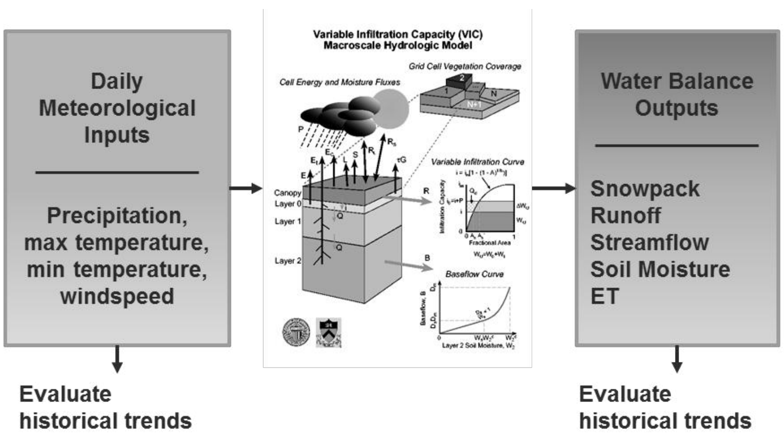


Figure 3-6. Summary of approach for assessment of historical surface water availability

For the Klamath River Basin Study, current and future water supply assessments rely on the variable infiltration capacity (VIC) model for simulation of surface water hydrology. The VIC model (Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) is a grid-based hydrologic model that solves the water balance at a spatial scale of 1/8th degree, or approximately 10 kilometers on a side. Details regarding the VIC model and the configuration used in the Klamath River Basin water supply assessment are provided in Appendix B, Supplemental Information for Assessment of Water Supply; however, details relevant to this study are provided below.

The VIC model requires gridded daily precipitation, maximum and minimum temperatures, and wind speed magnitude (at a minimum) as input to simulate water balance variables. The Klamath River Basin Study utilizes historical gridded observations developed by Maurer et al. (2002) for the period from January 1949 to July 2000. Additional model forcings that drive the water balance, such as solar (short-wave) and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficit, are calculated within the model.

The VIC model outputs may be defined by the user, but typically include grid cell water balance terms such as evapotranspiration, baseflow, or runoff. Gridded surface runoff and baseflow are hydraulically routed to produce streamflow at a select group of locations, using the model presented by Lohmann et al. (1996). Routed streamflow using this approach represents natural streamflow – that is, streamflow that would occur in the absence of water management (i.e., diversions, return flows, and storage). For climate change impact studies, VIC is commonly run in water balance mode due to its higher computational efficiency compared to the alternative energy balance mode, which facilitates numerous projected climate simulations.

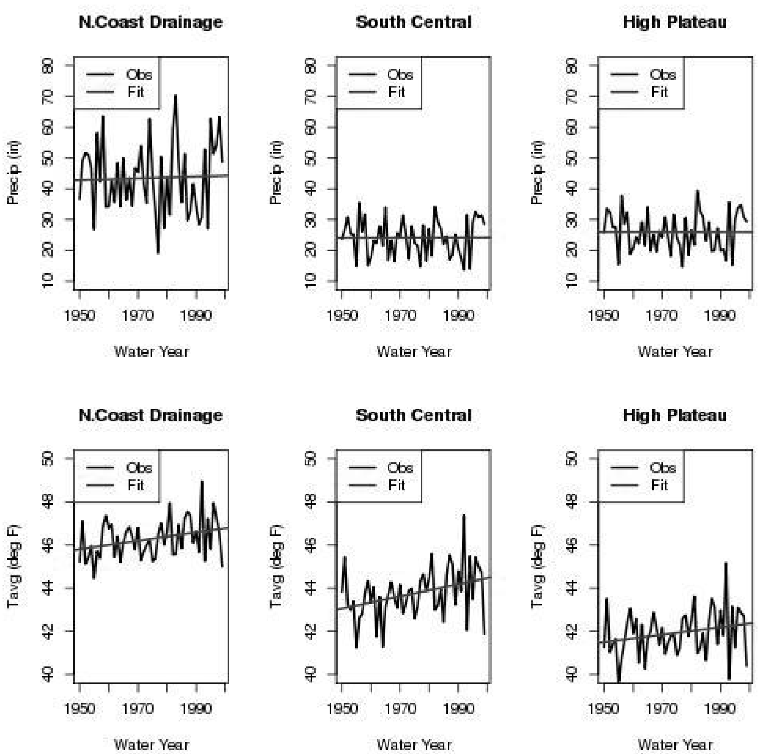
3.3.3 Present Availability and Historical Trends

This section summarizes present climate and surface water availability as well as historical trends. Historical simulated trends in climate and water balance variables are based on data used in the Klamath River Basin water supply assessment. The trends presented for climate (precipitation and temperature) likely have less uncertainty than those based on water balance parameters, primarily because climate trends were computed based on interpolated observations whereas water balance trends were computed based on hydrologic model output. Where appropriate, results are compared with findings from previous studies.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. For example, this dataset was used to develop climate and hydrologic projections developed and supported by Reclamation as part of its West-Wide Climate Risk Assessment (Reclamation, 2011d) and data portal (Archive Collaborators, 2000). The dataset has been extended beyond the original July 2000 date to December 2010 (Maurer et al., 2010). However, we utilized the original dataset as the basis for evaluating historical hydrology in the region to maintain consistency with previous efforts.

Historical trends in April 1 SWE, total annual runoff, total annual evapotranspiration, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model described briefly in the previous section. Because summer months typically receive low precipitation in the Klamath River Basin (see Table 3-1), soil moisture is an important water source

for natural vegetation and perhaps some dryland agriculture. Hence, the Klamath River Basin Study Water Supply Assessment reports trends in June 1 soil moisture, which was found to be the month with maximum soil moisture in the greater watershed. Trends were computed over the entire Klamath River Basin, as well as over the three dominant climate divisions within the basin: North Coast Drainage, South Central, and High Plateau. The fourth climate division within the watershed, Southwestern Valleys, covers only a small portion of the watershed (spanning just five spatially distributed VIC model grid cells). Therefore, data for this region is not summarized.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

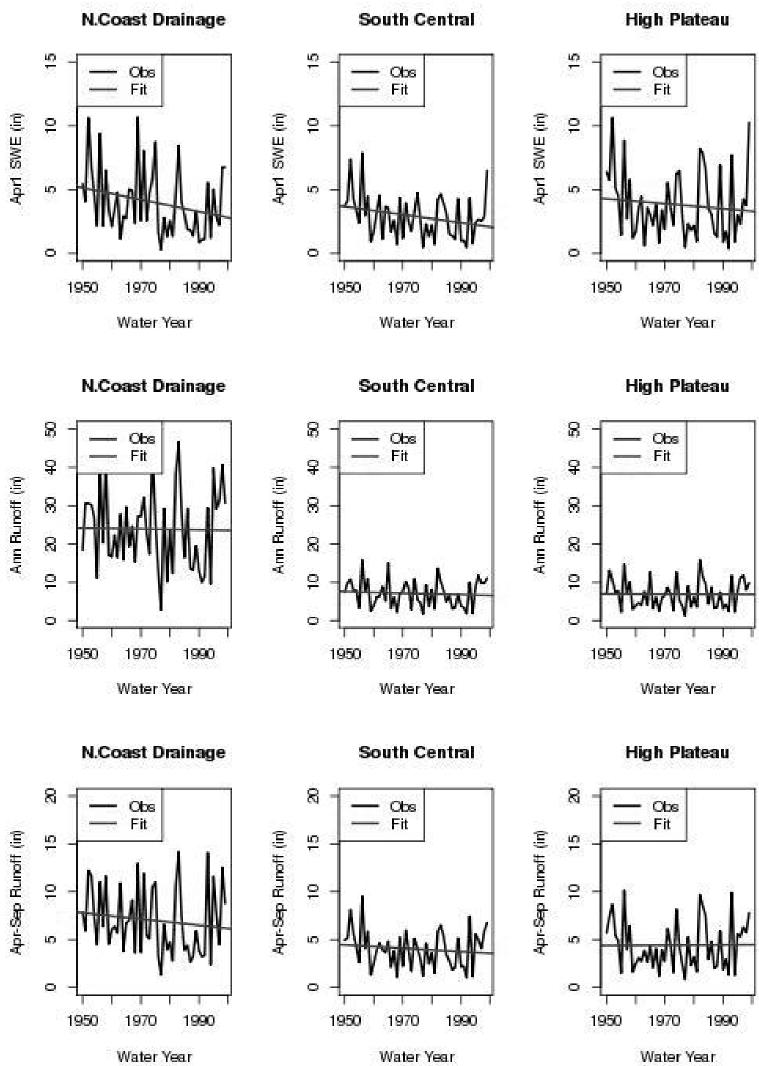
Figure 3-7. Trends in mean annual water balance parameters (precipitation and temperature) over 1950–1999 water years

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50-year period), small but increasing trends over the portions of the basin within the North Coast Drainage and South Central Climate Division (about 1.3 inches [+3 percent] and +0.1 inches [+0.5 percent] over the 50-year period, respectively), and a small decreasing trend over the portion of the basin within the High Plateau Climate Division (-0.03 inches [-0.1 percent]). None of these historical trends is statistically significant at the 95th percentile level (see Figure 3-7 and Table 3-3 for a summary of trends). The combination of both increasing and decreasing historical trends in precipitation over parts of the watershed is consistent with previous findings (Hoerling et al., 2010) showing a lack of clear historical change signal for annual precipitation.

All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999 (Figure 3-7 and Table 3-3). The trends in those portions of the basin within the North Coast and South Central climate divisions, as well as in the basin as a whole, are statistically significant at the 95th percentile level. Historical trends in mean annual temperature (+1 degree F basin-wide and +0.8 to +1.4 degrees F, depending on the climate division) are consistent with previous findings indicating positive change in temperature (Moser et al., 2012; Furniss et al., 2012).

Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide as well as for each of those portions of the basin within the North Coast, South Central, and High Plateau climate divisions (see Figure 3-8 and Table 3-3). Historical trends basin-wide indicate about a 41 percent decrease in April 1 SWE, with a range of about 22 percent to 45 percent over the portions of the basin within the three dominant climate divisions. The range of historical decreases in SWE computed by this study closely corresponds with the reported decrease in Upper Klamath Basin April 1 SWE by Mayer and Naman (2011) of 40 percent over the period 1961–2009, using snow course measurements below about 6,000 feet. Although the computed declines in April 1 SWE may be considered substantial, none are statistically significant at the 95th percentile level.

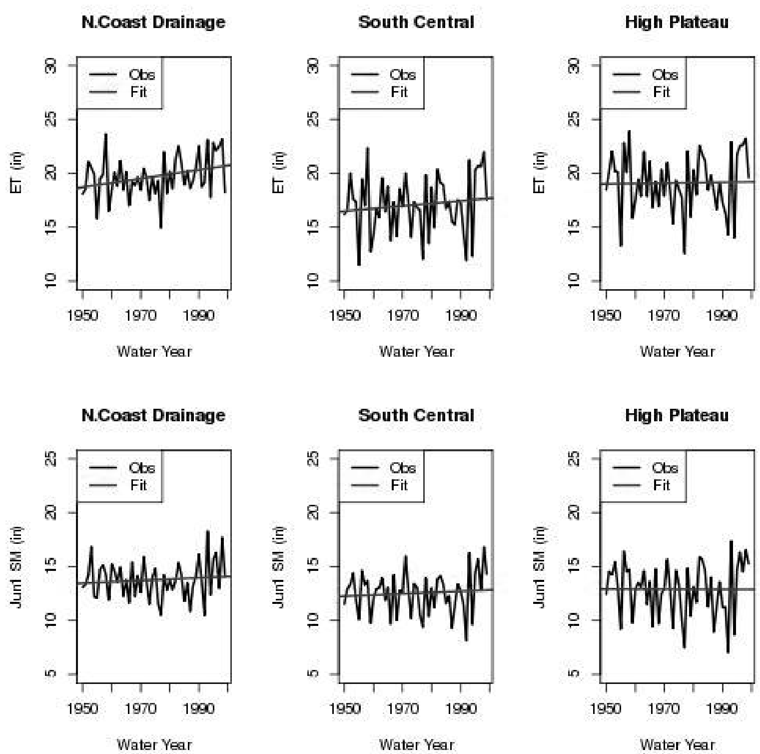
Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent, with a range of 4 to 22 percent depending on the climate division (see Figure 3-8 and Table 3-3). Mayer and Naman (2011) reported larger declines in streamflow over the 1961–2009 period (16 to 38 percent), albeit over spring and summer months only. None of the computed trends in runoff (regional or basin-wide) are statistically significant at the 95th percentile level.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

Figure 3-8. Trends in mean annual water balance parameters (April 1 SWE, annual runoff, and irrigation season runoff) over 1950–1999 water years

Evapotranspiration (ET), as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide (see Figure 3-9 and Table 3-3). Portions of the basin within the three dominant climate divisions indicate a range of increase from about 1 percent in the High Plateau region to 11 percent in the North Coast Drainage region. The increase in ET is statistically significant at the 95th percentile level for the North Coast Drainage climate division only.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

Figure 3-9. Trends in mean annual water balance parameters (annual evapotranspiration and June 1 soil moisture) over 1950–1999 water years

Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole, yet the trends by climate division range from a decrease of about 0.3 percent in the High Plateau region to an increase of 5 percent in the South Central region and an increase of 4 percent in

the North Coast Drainage region (Figure 3-9 and Table 3-3). These trends are not statistically significant at the 95th percentile level.

Table 3-3. Mean change over 1950–1999 period (water years) by climate division within the Klamath River Basin and basin wide

	Basinwide		N Coast Drainage		South Central		High Plateau	
Precip	+0.8in	+2%	+1.3in	+3%	-0.1in	+0.5%	-0.03 in	-0.1%
Tavg	**+1°F**	**--**	**+1.0°F**	**--**	**+1.4°F**	**--**	**+0.8°F**	--
April 1 SWE	-2.0in	-41%	-2.3in	-45%	-1.6in	-42%	-1.0 in	-22%
Annual Runoff	-0.5in	-7%	-0.5in	-6%	-0.6in	-22%	-0.1 in	-4%
Apr-Sep Runoff	-1.2in	-18%	-1.6in	-20%	-0.9in	-19%	+0.1in	+2%
Annual ET	+1.5in	+8%	**+2.0in**	**+11%**	+1.2in	+7%	+0.2 in	+1%
June 1 Soil Moisture	0.4in	+3%	+0.6in	+4%	+0.6in	+5%	-0.03 in	-0.3%

Note: Numbers in bold indicate statistical significance of trends at the 95th percentile level.
Precip =mean annual precipitation/ Tavg = mean daily average temperature; SWE = snow water equivalent; ET = evapotranspiration

As previously mentioned, computed trends are highly dependent on the time period over which they are calculated. The primary reason for the dependence on duration is that, coincident with the low frequency trends resulting from human-induced climate change, there are various patterns of natural climate variability. Temporal patterns of climate variability in the Northwest are strongly influenced by variations over the Pacific Ocean, chiefly El Niño/Southern Oscillation (ENSO). ENSO involves linked variations in the tropical Pacific Ocean and overlying atmosphere. During the El Niño phase of ENSO the wintertime jet stream tends to split, with warmer air flowing into the Northwest and Alaska and a southern branch of the jet stream directing unusually frequent and heavy storms toward southern California. During the El Niño winter and spring, Oregon's climate is slightly more likely than usual to be warm and dry. The Pacific Decadal Oscillation (PDO) is another pattern of climate variability that acts similarly to ENSO, but typically over longer time frames (on the order of multiple decades). Depending on the time period chosen for trend analysis, patterns of natural climate variability may mask or

Historical Surface Water Availability

Of historical precipitation, temperature, snowpack, runoff, evapotranspiration, and soil moisture, the only statistically significant trends at 95th percentile level are:

Temperature (all regions) and evapotranspiration (North Coast Climate Division).

amplify the apparent trends due to human-induced climate change. Choosing longer time periods over which to compute historical trends can help to reduce the relative influence of natural climate patterns on the computed trends.

3.4 Historical Groundwater Availability

For analysis of groundwater impacts of climate change, outputs from surface water hydrology simulations, informed by climate projections, may be used as inputs to groundwater models. For the Klamath River Basin Study, groundwater hydrology is simulated using the USGS MODFLOW, or moderate finite-difference flow model, over the Upper Klamath Basin (upstream of Iron Gate Dam), developed through studies by Gannett et al. (2007, 2012). This model simulates evapotranspiration, groundwater head, and discharge to streams, among other things. Groundwater hydrology is also simulated in the Scott and Shasta Valleys using a multiple regression-based tool. This groundwater simulation tool performs an overall water balance to simulate relative groundwater levels. This modeling tool may be used to evaluate projected changes in the overall water balance of these river systems, as well as to evaluate the effects of projected changes in streamflow on the groundwater system.

3.4.1 Previous Studies

Groundwater modeling studies have been previously conducted for parts of the Klamath River Basin including the Upper Klamath Basin (Gannett et al., 2007, 2012) and the Scott River Valley (S.S. Papadopulos & Associates, Inc., 2012). Additional groundwater modeling efforts are currently underway, including research studies in the Scott and Shasta Valleys by faculty and graduate students at the University of California at Davis (Harter and Hynes, 2008). These studies are further described below.

3.4.1.1 Upper Klamath Basin

Gannett et al. (2007, updated in 2010) completed a groundwater investigation of the Upper Klamath Basin, upstream of Iron Gate Dam, to improve understanding of the groundwater dynamics in the region. The investigation was based on collected data, monitoring, and analysis. Since 2001 the basin has experienced increased groundwater pumping, particularly within and near Reclamation's Klamath Project, in response to various biological opinions and court orders. A water bank program administered by Reclamation, as well as subsequent Klamath Water and Power Agency Water Use Management Plans, have purchased varying quantities of groundwater to supplement surface water in 8 of the past 11 years (2003 through 2013). The water bank provided incentives for irrigators to increase groundwater pumping during years of low surface water availability as a pathway for retaining greater instream flows.

In a subsequent study by Gannet et al. (2012), in collaboration with the OWRD and Reclamation, a MODFLOW finite-difference groundwater model was developed to represent the system and to improve understanding of the long term

effects of the above-described water banking program. In this investigation, the authors sought to identify the optimal strategy for meeting user needs while not exceeding defined impact constraints. This study found that some supplemental groundwater pumping could occur while not exceeding defined constraints, and that groundwater levels should recover from the observed declines if pumping was reduced to pre-2001 rates.

3.4.1.2 Scott Valley

A groundwater study for the Scott Valley (tributary region to the Klamath River, see Figure 3-13) was completed by S.S. Papadopulos & Associates, Inc. in 2012 for the Karuk Tribe. The study examined the impacts of groundwater pumping on the aquifer and on the Scott River by evaluating groundwater levels under three scenarios including recent use conditions, an alternative water use condition representing partial build-out of the existing groundwater capacity, and partial build-out with gradual increases in pumping levels.

Results from the study indicated that long-term declines in groundwater levels were minimal in winter and greater in late summer, corresponding with seasonal groundwater pumping. The declines can, and have, impacted streamflows. The model was used to develop a relationship between groundwater levels and stream depletions, showing that increases in groundwater pumping result in reductions in streamflow mostly within the first year or two (S.S. Papadopulos & Associates, Inc., 2012).

Researchers at the University of California, Davis completed the Scott Valley Community Groundwater Study Plan (Harter and Hynes, 2008, hereafter referred to as the UC Davis Groundwater Study Plan), which discusses the motivation for the approach of their ongoing groundwater modeling study for the Scott Valley. The study is being conducted in cooperation with Siskiyou County and Scott Valley stakeholders as a result of recommendations made in the TMDL Action Plan (State of California, 2005) and the Scott River Watershed Council Strategic Action Plan (Scott River Watershed Council, 2005). The State of California has determined that the water quality standards for the Scott River are exceeded due to excessive sediment and elevated water temperature. Studies on which the TMDL Action Plan is based state that groundwater inflows are a primary driver of stream temperatures in the Scott Valley, along with human-caused changes in riparian shading.

The UC Davis Groundwater Study Plan identifies a number of statements, hypotheses, and research questions that will be addressed during the study. A couple of noteworthy statements include: (1) there is a statistically significant correlation between SWE, total annual precipitation, and average Scott Valley groundwater table elevation in subsequent months/years, and (2) the magnitude and dynamics of seasonal and intra-annual groundwater level fluctuations have significantly changed since 1950.

The S.S. Papadopulos & Associates (2012) modeling study and the ongoing UC Davis groundwater study rely on a survey of geology and groundwater features of the Scott Valley conducted by the USGS in 1958 (Mack, 1958). The report describes in detail the geologic features in the basin and points out some interesting features of the groundwater system. Most of the wells in the area are shallow dug wells, averaging about 25 feet. Recharge to groundwater comes in the form of rainfall, seepage from tributary streams, and irrigation. Losses from groundwater come mainly in the form of evapotranspiration and hyporheic flow into the Scott River. Mack estimated the storage capacity in the flood-plain sediments to be about 220,000 acre-feet. As part of the Mack (1958) study, a number of groundwater level measurements were made either from existing or installed monitoring wells. A number of these wells continued to be used as monitoring wells. These data serve as a primary data source for subsequent Scott Valley groundwater modeling studies, including the current study presented in this chapter.

3.4.2 Approach – Upper Klamath Basin

Groundwater in the Upper Klamath Basin is being simulated using the USGS MODFLOW finite-difference model developed by Gannett et al. (2012). Details of the model configuration may be found in the mentioned study; however, a general discussion is included here. Emphasis in this discussion is placed on two elements of the model with direct linkages to the surface water hydrologic model developed over the region (VIC). The approach discussed below helps to provide context for the approach of evaluating the impacts of projected climate.

The MODFLOW model developed for the Upper Klamath Basin has 100,070 active cells and a historical simulation period of water years 1970 through 2004 (October 1969–September 2004). For the purposes of this study, and to maintain consistency with datasets used to evaluate surface water supply, the historical period was modified to water years 1970 to 1999. The model has quarterly stress periods (every 3 months) and each stress period is divided into five equal timesteps. Model input data are developed on a quarterly basis (i.e., disaggregation to individual timesteps occurs internally within the model).

The MODFLOW model utilizes a number of packages that help to improve its representation of physical processes. The packages implemented in this configuration include the recharge package, well package, stream package, general head boundary package, evapotranspiration package, drain package, and reservoir package, in addition to the basic package. There are two primary linkages with surface water inputs, such as outputs from the VIC surface water hydrologic model. First, VIC model precipitation inputs are used to develop seasonal relationships between precipitation and recharge, which are later used to develop scenarios of future recharge based on projected precipitation. Second, VIC simulated potential evapotranspiration (PET) and actual ET are used to compute the upper threshold for ET used by the MODFLOW model (computed as the difference between PET and actual ET). The modeling study conducted by

Gannett et al. (2012) relied on surface water inputs from the USGS Precipitation Runoff Modeling System (PRMS), developed over the same region.

Assessment of historical groundwater levels in the Upper Klamath Basin primarily comes from the modeling efforts by Gannett et al. (2012). However, as part of the assessment of groundwater supplies, the MODFLOW model was rerun over the modified historical period and is the baseline for comparison of projected groundwater levels.

3.4.3 Present Availability and Historical Trends – Upper Klamath Basin

Present availability and historical trends in groundwater elevation and recharge are discussed in the context of previously completed work by Gannet et al. (2012). The historical MODFLOW simulation described by Gannett et al. (2012) was used as the historical baseline for the assessment of groundwater in the Upper Klamath Basin for this water supply assessment.

Historical availability of groundwater is presented in this section with respect to recharge and groundwater elevations. Historical recharge to the groundwater system was developed by Gannett et al. (2012) using summed subsurface flow (interflow) and groundwater flow terms from the PRMS model. Subsurface (interflow) generated by PRMS represents shallow rapid subsurface flow, which is not well simulated by MODFLOW. Therefore, adjustment factors were applied to the summed recharge values to more accurately simulate recharge in the basin. The resulting historical recharge used as input to the MODFLOW model is illustrated by Figure 3-10.

The highest recharge, according to Figure 3-10, is along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains. The lowest recharge amounts are in the central and southern parts of the basin. It should be noted that amount of recharge does not necessarily correspond to areas with highest ground permeability. Discussions from Section "Upper Klamath Groundwater Basin", addressing groundwater characteristics of the basin, indicate that the western part of the basin is generally characterized by low permeability, while parts of the central basin are characterized as having high permeability and high groundwater yield. Greater recharge occurs along the western boundary primarily due to the fact that there is more water available for recharge, compared with the central portion of the basin.

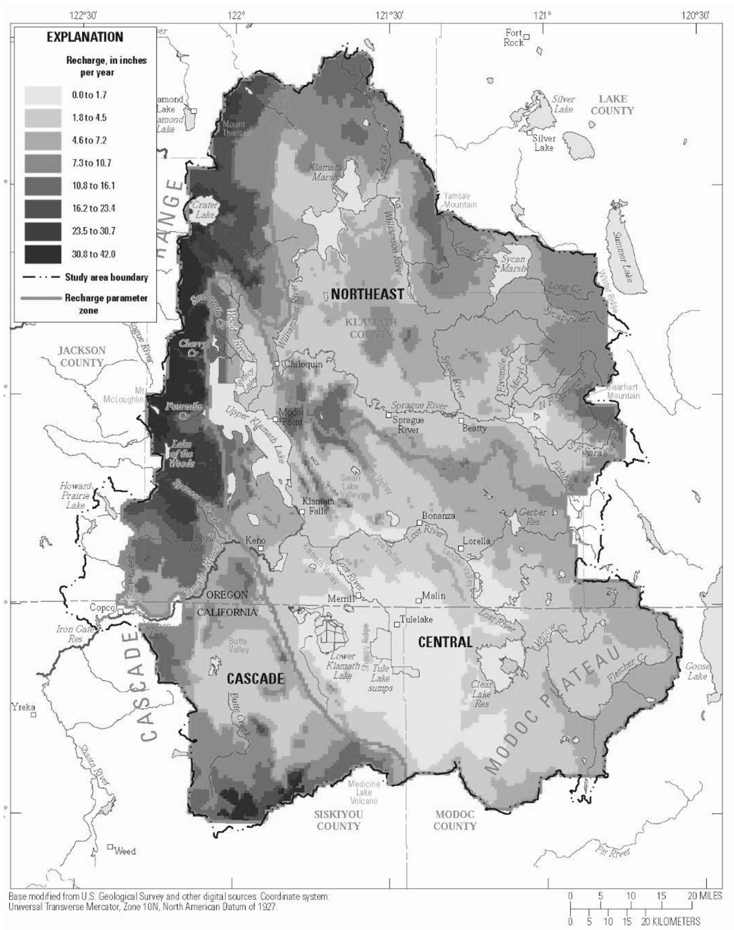


Figure 7. Estimated mean annual groundwater recharge from precipitation in the upper Klamath Basin, Oregon and California, 1970–2004, in inches, and recharge parameter zones.

Source: Figure 7 from Gannet et al., 2012

Note: Recharge Zone 1 (Cascade) lies along the western boundary of the basin. Recharge Zone 2 (Northeast) covers the northeastern part of the basin. Recharge Zone 3 (Central) covers the central and southeastern part of the basin.

Figure 3-10. Summary of mean annual recharge over the Upper Klamath River Basin

Gannett et al. (2012) also summarizes historical simulated groundwater elevations, compared with observations, for a number of sites throughout the Upper Klamath Basin model domain. We provide a sample of figures for two sites, including the Wood River sub-basin, located upstream of Upper Klamath

Lake (Figure 3-11) and the Lower Klamath Lake sub-basin, located in the southcentral portion of the model domain (Figure 3-12).

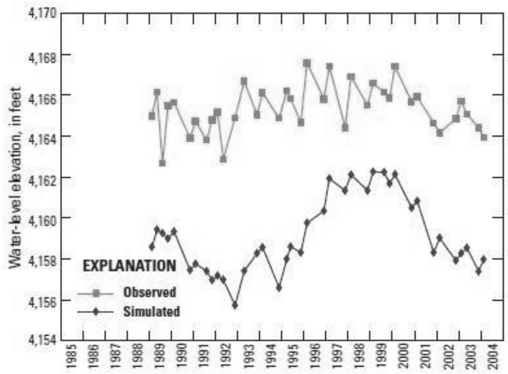


Figure 18. Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

Source: Figure 18 from Gannett et al., 2012

Figure 3-11. Observed and simulated water-level elevations in the Wood River sub-basin

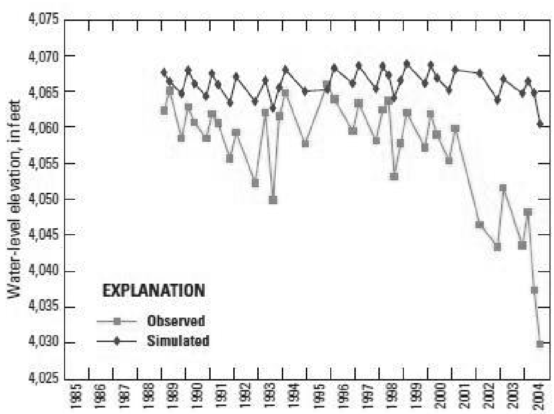


Figure 36. Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

Source: Figure 36 from Gannett et al., 2012

Figure 3-12. Observed and simulated water-level elevations in the Lower Klamath Lake sub-basin

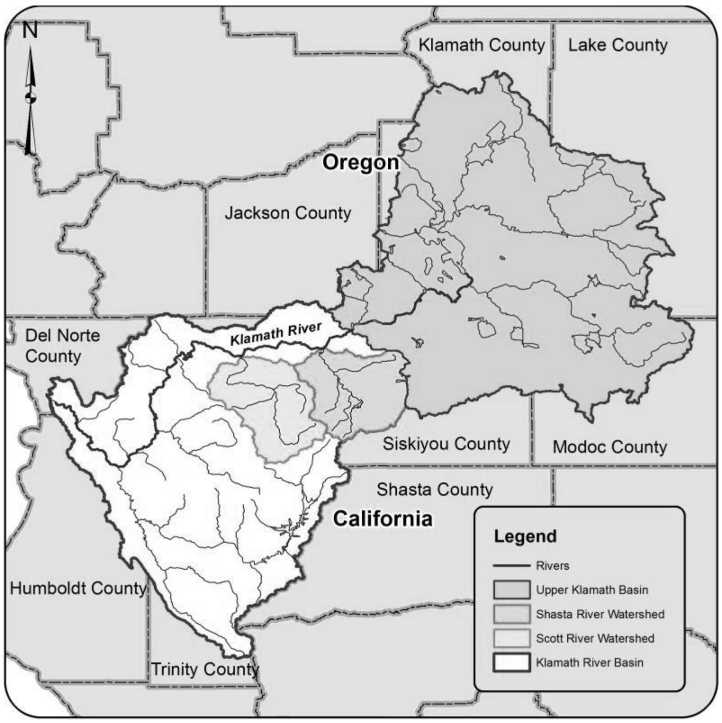
Results for these two sites are representative of the types of calibration results for the MODFLOW model. In general, the model captures the low frequency variability in groundwater levels over the period from the late 1980s through 2004. The model is also able to capture much of the year-to-year variability in groundwater levels. The difference between simulated and observed groundwater elevations can vary from on the order of 5 feet to 30 feet, depending on the site and year. Gannett et al. (2012) suggest the larger differences (seen in parts of the Wood River sub-basin as shown on Figure 3-11, for example) may be due to the coarse vertical discretization of the model, relative to the gradients of groundwater flow. Also for the Lower Klamath sub-basin site (Figure 3-12), the model is not able to capture the decline in observed groundwater elevation that occurs after about 2000 (corresponding with drought and increases in pumping). Differences between observed and simulated groundwater elevations may be attributed, at least in part, to lack of accurate information on rates and locations of pumping in some parts of this sub-basin (Gannett et al., 2012).

Historical Groundwater Availability – Upper Klamath Basin

The highest recharge to groundwater occurs along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains, while the lowest recharge amounts are in the central and southern parts of the basin.

3.4.4 Approach – Scott and Shasta Valleys

The groundwater portion of the Klamath River Basin Study water supply assessment consists of analysis for three main regions within the Klamath River Basin: the Upper Klamath Basin, the Scott Valley, and the Shasta Valley (see Figure 3-13). These regions represent the majority of groundwater use in the Klamath River Basin, as inferred from defined groundwater regions from California's Groundwater Bulletin 118 (CDWR, 2003). To the extent possible, these analyses rely on existing modeling tools and data.



Sources: Principal Aquifers, http://www.nationalatlas.gov/mld/aquifrp.html; Scott and Shasta Valley Well Data, http://www.water.ca.gov/waterdatalibrary/groundwater/index.cfm.

Figure 3-13. Map of modeled groundwater basins within the Klamath River Basin

Existing groundwater modeling tools for the Scott and Shasta Valleys were explored in the preparation of this water supply assessment. No existing groundwater modeling tools were identified for the Shasta Valley, although there are ongoing studies at the University of California at Davis related to groundwater dynamics of the Shasta Valley.[3] There is also an existing draft groundwater data needs assessment developed by CDWR which has not been finalized (CDWR, 2011). The existing groundwater model for the Scott Valley, developed by S.S. Papadopulos & Associates, Inc. (2012) for the Karuk Tribe, was explored for possible use in the Klamath River Basin Study. However, use of this modeling tool was deemed infeasible due to the reasons outlined below:

[3] http://hsgg.ucdavis.edu/research/student-abstracts/

1. The modeling tool was not readily available for use by Reclamation. In other words, additional funding would have been required to either contract with S.S. Papadopulos & Associates, Inc. to participate in the study or fund them to package the model for use by Reclamation staff.
2. The model was designed with a relatively narrow focus on the impact of groundwater pumping on streamflows.
3. Confidence in the results from a sophisticated MODFLOW finite-difference groundwater model for the Scott Valley, where input data are limited, was not high enough to justify the cost of its implementation in the study.
4. The spatial resolution of the surface water hydrologic model that provides surface water inputs to the groundwater model is coarse in comparison with the size of the Scott River Basin, which also limits confidence in the utility of applying a sophisticated MODFLOW model in the basin.

Conceptual regression-based groundwater screening tools were developed for both the Scott and Shasta Valleys based on the approach taken by Reclamation (2013) in the Santa Ana Watershed Basin Study. The added advantage of developing these tools is consistency in the approach for the two neighboring watersheds. This section briefly describes the groundwater screening tool as it was applied in this Klamath River Basin Study. Details regarding data used as input to the Scott and Shasta Valley tools are described in Appendix B, Supplemental Information for Assessment of Water Supply.

The regression-based groundwater model relies on historical inflows and outflows from the groundwater system, estimated from available data, including spatially distributed recharge from precipitation, focused recharge from stream and canal seepage losses or deep percolation of irrigation water, groundwater abstraction by pumping, and other inflows and outflows. The model is calibrated and verified with respect to available observations. The model may then be applied using projected future conditions, as well as applied management alternatives, to evaluate the effects of climate change and adaptation strategies on groundwater resources.

The groundwater screening tool estimates fluctuations in basin-scale groundwater levels in response to natural and anthropogenic drivers, including climate and hydrologic conditions, agricultural land use, municipal water demand, and trans-basin water imports, if applicable. The tool allows users to quickly estimate basin-scale groundwater conditions under a broad range of future scenarios and provides insight into the primary factors driving basin-scale groundwater fluctuations.

This screening tool is based on a conceptual model which considers fluctuations in basin-average groundwater elevations as a function of basin-scale drivers.

These drivers are illustrated in Figure 3-14 and may be categorized by the following: water availability (precipitation, local streamflow, and trans-basin imports), water demand (municipal and industrial demand, agricultural land use, and evaporative demand), and an optional exogenous input that represents groundwater management objectives that affect basin-scale groundwater levels. As a result, use of the groundwater screening tool does not require detailed information regarding local hydrologic, geologic, climatic, and anthropogenic factors that may affect local groundwater fluctuations. However, it should be noted that as a result of this basin-scale approach, the groundwater screening tool is primarily applicable at the scale of individual groundwater basins or sub-basins, where the effects of local-scale conditions are largely averaged out and where subsurface inflows and outflows from surrounding areas are negligible.

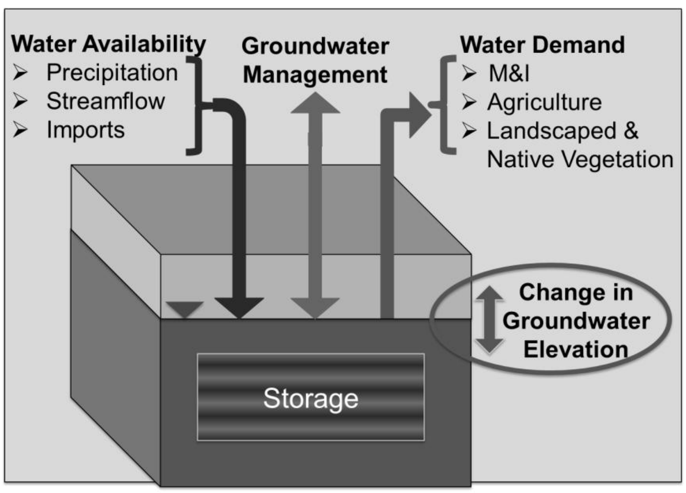
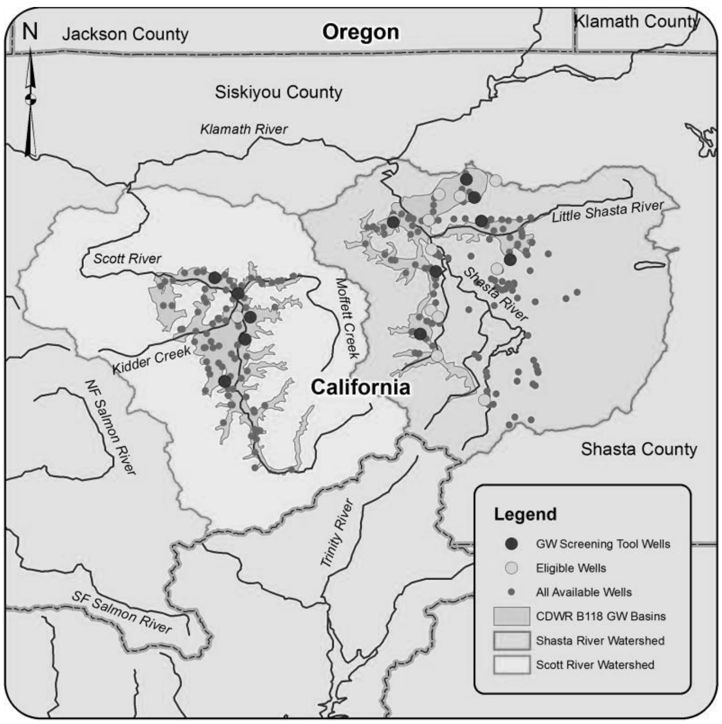


Figure 3-14. Conceptual model of basin-scale groundwater fluctuations used in developing the groundwater screening tool

The model domains for the Scott and Shasta Valleys correspond with groundwater basins defined by CDWR's Bulletin 118 (CDWR, 2003). CDWR Bulletin 118 was first created in the 1950s as a means for collection and evaluation of groundwater data throughout California. Bulletin 118 has been updated numerous times, with the latest update in 2003. Bulletin 118 has defined groundwater basins, including one each for the Scott and Shasta Valleys. Scott and Shasta Valley groundwater basins roughly correspond with the unconsolidated sand and gravel PNW Basin-fill aquifers from the USGS (2003) National Atlas of Principal Groundwater Aquifers[4] map. The Bulletin 118

[4] http://www.nationalatlas.gov/wallmaps.html#aquifers

groundwater basins define the model domain for the groundwater screening tools for the Scott and Shasta Valleys. These groundwater basins are illustrated in Figure 3-15.



Note: The map shows all available wells (grey), eligible wells3 (pink), and wells[3] used in development of the groundwater screening tools for both watersheds (red).

Figure 3-15. Map of CDWR Bulletin 118 groundwater basins for the Scott and Shasta River basins

Historical data were used to determine regression coefficients and to evaluate model performance over the historical period (1980–1999). For this study, historical groundwater elevation data averaged over each groundwater basin were used to fit the regression models. These data came from CDWR and USGS data archives. Monthly mean groundwater elevations were calculated from the available instantaneous measurements. Note that for the Scott and Shasta Valleys, well measurements typically occurred once in the spring and once in the autumn, and interpolated monthly time series were computed from these measurements. Well data were screened for individual outliers and analyzed to determine whether the groundwater elevations at the well are representative of the

average behavior of each groundwater basin (Scott and Shasta). Steps were taken to avoid potential biases due to variations in the period of record between wells, and outlier wells that are not representative of large-scale groundwater fluctuations within a basin. Additional details are provided in Appendix B, Supplemental Information for Assessment of Water Supply, regarding the sources of well data, methods for screening the data, and methods to account for potential biases in well records. Inputs of precipitation, evaporative demand, and streamflow were computed based on VIC model simulations, aggregated to a monthly timestep and averaged over each groundwater basin. Demands such as agricultural and municipal, domestic, and industrial demand were developed based on available data described in detail in Appendix B, Supplemental Information for Assessment of Water Supply. Note that aquifers outside of CDWR Bulletin 118 and well data not archived by CDWR or USGS were not considered as part of this modeling study, which may present limitations in the applicability of the modeling tools to simulate basin-wide behavior.

3.4.5 Present Availability and Historical Trends – Scott and Shasta Valleys

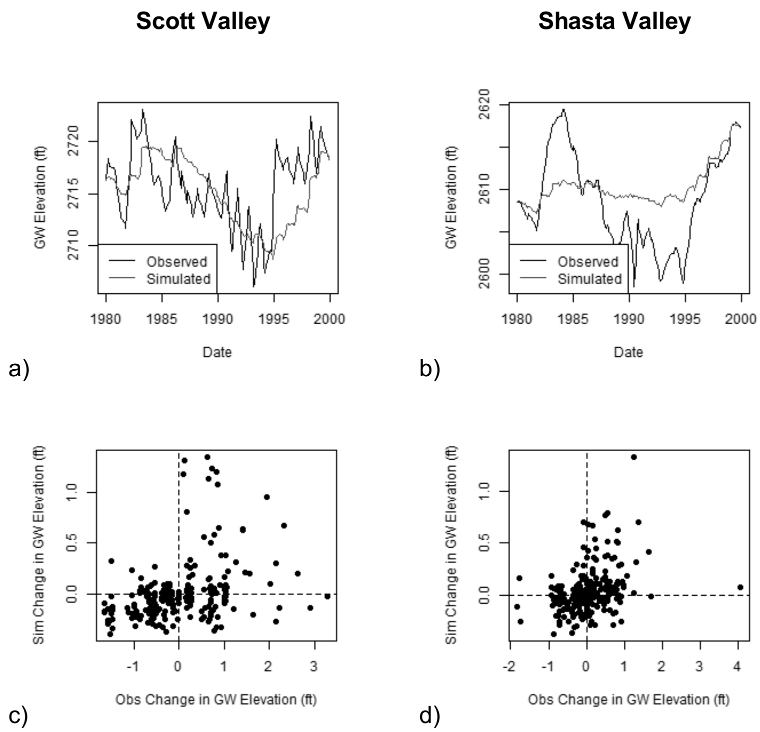
The groundwater screening tool was applied to the groundwater basins in the Scott and Shasta watersheds that were defined by CDWR Bulletin 118 (CDWR, 2003) and are shown on Figure 3-15. There is one defined groundwater basin for each of the watersheds. The screening tools were fit using a linear regression model to the collected observed data (see Equation 1 in Appendix B, Supplemental Information for Assessment of Water Supply). The models were then verified by exploring variations of the groundwater elevation input data. The regressions were tested to ensure that well data used most closely represented basin-wide behavior. Correlations of observed groundwater elevation with individual model inputs were explored and statistically significant correlations (at the 95th percentile confidence level) were found between observed groundwater elevation, precipitation, and runoff for some wells (but not all), indicating that groundwater levels in the Scott and Shasta Valley CDWR Bulletin 118 aquifers are related to climatic fluctuations.

> **Historical Groundwater Availability – Scott and Shasta Valleys**
>
> The statistical groundwater screening tools may be applicable for evaluating the relative impacts of climate change amounts in the central and southern parts of the basin.

Figures 3-16 (a) and (b) illustrate observed and simulated basin-averaged groundwater elevation for the Scott and Shasta groundwater basins, respectively, for the period 1980–1999. The figures show that the groundwater screening tools capture the larger frequency fluctuations (i.e., multi-year trends) in groundwater

elevation, but are not able to resolve finer interannual fluctuations. Both groundwater basins experienced declines in groundwater elevation during the late 1980s and early 1990s on the order of about 20 feet, corresponding with lower precipitation and streamflow during that period. Observed groundwater elevations in the Scott Valley have ranged between about 2,705 feet and 2,725 feet, while observed groundwater elevations in the Shasta Valley have ranged between about 2,600 feet and 2,620 feet. Interannual fluctuations may be driven by local-scale non-linear processes that are not represented in the basin-scale screening tool, or by management activities (for example, pumping) that are not included in this analysis.

Figures 3-16 (c) and (d) illustrate observed change in groundwater elevation versus simulated change in groundwater elevation. They graphically show the data points on which the linear regressions for the groundwater screening tools are based. Model fit statistics summarized in Table 3-4 show that for both the Scott and Shasta Valleys, the screening tools are able to explain a little more than 10 percent of the variance in the data (coefficient of determination, or R^2, of 0.11 and 0.12, respectively, for Scott and Shasta groundwater basins). A more robust model would have higher R^2 values. The degree of model fit indicates that the tool may be applicable for evaluating the relative impacts of climate change, but is not applicable for evaluation of short-term management decisions. In the future, additional and improved data sources may help to improve model fit and thereby the applicability of the tool for a range of purposes.



Note: (a) groundwater elevation for the Scott groundwater basin; (b) groundwater elevation for the Shasta groundwater basin; (c) groundwater elevation change for the Scott groundwater basin; (d) groundwater elevation change for the Shasta groundwater basin

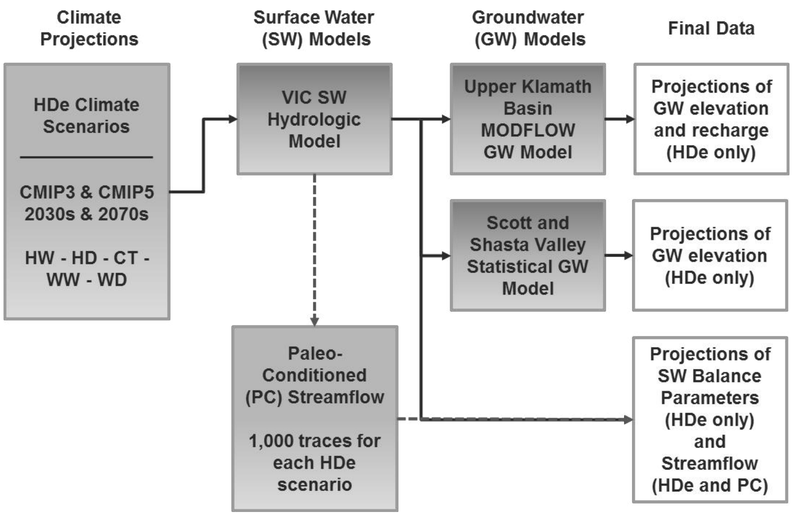
Figure 3-16. Simulated and observed Scott and Shasta basin groundwater elevations, as well as simulated and observed changes in groundwater elevations

Table 3-4. Summary of model fit for Scott and Shasta groundwater basin screening tools

Statistic	Scott Groundwater Basin	Shasta Groundwater Basin
Multiple R2	0.11	0.12
Adjusted R	0.33	0.35
P-value	0.0000511	0.0000101
Residual Standard Error	0.838	0.5905

3.5 Effects of Climate Variability and Change on Supply

This section builds upon tools developed for assessment of historical supplies and provides a detailed discussion of the approach for developing and utilizing future climate scenarios to evaluate projected changes in surface and groundwater. A diagram illustrating the overall approach for evaluating the effects of climate change on water supply is provided in Figure 3-17. Details regarding data linkages between steps are provided in the next section.



Note: HDe refers to ensemble hybrid delta climate scenarios; PC refers to paleo-condition streamflow projections.

Figure 3-17. Summary of approach for evaluating the effects of climate change on surface water and groundwater supplies

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020 through 2049) and 2070s (represented by the mean from 2060 through 2089). In evaluating the effects of climate change on water supply, projections of future supply are commonly compared with that of a historical reference period. The historical reference period for the Klamath River Basin Study is 1970–1999. It should be noted that historical climate has not changed steadily through the 20th century. Basin average temperature has increased from the 1970s through the rest of the century, following an approximate 40-year period of relatively steady temperatures. Basin annual precipitation has fluctuated considerably during the past century, but was relatively steady from the 1940s

through the rest of the century (Reclamation, 2011c). Figure 3-7 illustrates historical trends from 1950 through 1999.

3.5.1 Approach

As a step toward greater understanding of the implications of climate change on the Klamath River Basin, this section first describes the approach for development of climate scenarios for the Klamath River Basin Study water supply assessment, followed by discussions of approaches for evaluation of climate change impacts on surface and groundwater supplies. With respect to surface water, the assessment focuses on projected changes in snowpack, timing and quantity of runoff, ET and soil moisture, and low streamflow periods that have major implications for fish and wildlife and the livelihoods of basin residents. With respect to groundwater, the assessment focuses on projected changes in groundwater recharge and discharge, as well as overall changes in groundwater elevations.

3.5.1.1 Climate Projections

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades as opposed to days or weeks. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings, both natural (such as volcanic eruptions, solar variations) and anthropogenic (such as changing atmospheric composition and land-use change). Climate variability describes deviations from mean climate that may be due to natural internal processes or to variations in natural or anthropogenic forcings. Natural variability includes multi-year cycles in climate such as El Niño and La Niña, as well as cycles that can occur on even longer time scales (for example, the PDO). Changes in climate due to natural variability will continue to occur in the future, along with changes due to increased greenhouse gas concentrations from human activities. Climate change may be differentiated from climate variability as the persistence of anomalous conditions.

> **Climate Projections**
>
> The Klamath River Basin Study utilizes climate projections from World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5).

The state of practice for evaluation of the long-term availability of water supply is to incorporate a range of approaches to characterize past and projected climate. The approaches may include use of paleo-conditioned climate data and use of projections from general circulation models (GCMs). Paleo-conditioned climate data are developed from long-term climatic records (such as tree rings, pollen, etc.) that have been used to capture the natural variability of climate over thousands of years.

Another approach involves downscaling information (in space and time) from native scale GCM resolution to a finer resolution suitable for watershed-scale climate change impact studies. This can be done using dynamical downscaling, which uses GCM output to define boundary conditions for a finer scale regional climate model, or statistical downscaling, which uses historical data as a way of statistically mapping GCM scale information to a finer resolution. Statistical downscaling may involve delta method experiments, which compute period change values based on GCMs and apply them as perturbation factors to historical data. Numerous variations exist within these three categories and there are also approaches that are hybrids of these categories.

The Klamath River Basin Study relies on data and modeling from Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). In that effort, Reclamation developed a consistent database of climate and hydrologic projections, with a focus on the 17 western states that fall within Reclamation's management domain. These projections are based on simulations from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3; Meehl et al., 2007), which are summarized in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007). Projections based on Phase 5 of the same model intercomparison project (CMIP5) reflect improvements in modeling of the Earth system since the CMIP3 effort and revised scenarios of global growth and greenhouse gas emissions. These simulations, which were made available in 2011, are summarized in IPCC's Fifth Assessment Report (Taylor et al., 2012). Both sets of projections, CMIP3 and CMIP5, are utilized as part of the Klamath River Basin Study water supply assessment.

Details regarding the approach for use of climate projections and development of climate scenarios for the Klamath River Basin Study are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, Figure 3-18 illustrates the overall approach for downscaling GCM projections to a finer spatial scale. The figure shows that a similar approach is taken regardless of the choice of CMIP3 or CMIP5 simulations: namely, emissions scenarios are incorporated into GCM simulations. These simulations are bias corrected at the resolution of the GCM and then statistically downscaled to the resolution of the Klamath River Basin Study hydrology models. Bias correction allows for the removal of systematic biases from GCM simulations, based on historical regional climate datasets derived from observations.

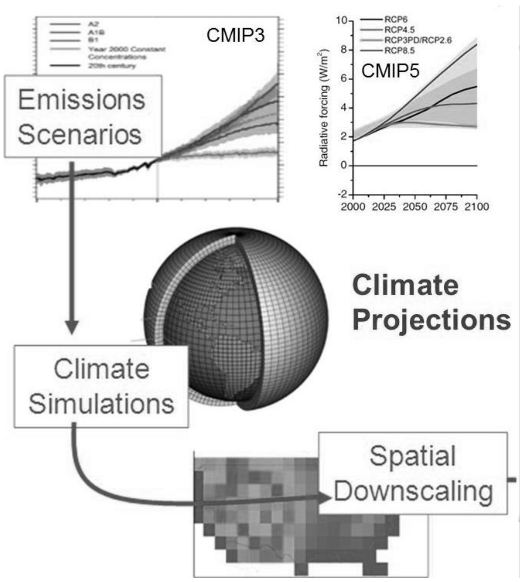


Figure 3-18. Downscaling elements

3.5.1.2 Deriving Climate Change Scenarios from Climate Projections

The high number of climate projections from CMIP3 and CMIP5 (on the order of hundreds of realizations) make their direct use in long term planning studies cost prohibitive in many cases. The Klamath River Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes the available suite of climate projections to derive a smaller number of climate change scenarios to inform long term planning.

The Klamath River Basin Study primarily utilizes climate scenarios that are derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d). The scenarios are developed based on both CMIP3 and CMIP5 statistically downscaled GCM projections, as these are considered equally likely potential climate futures at this time. Details regarding the approach for deriving climate scenarios from CMIP3 and CMIP5 climate projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, a brief overview is provided below.

The hybrid delta method approach for developing climate scenarios involves perturbing historical climate (precipitation and temperature) by change factors computed as the change in precipitation and temperature by month between a chosen future planning horizon and a baseline historical period (Reclamation, 2010). Change factors may be developed for each available downscaled climate projection (CMIP3 or CMIP5) or may be developed based on ensembles of climate projections. The Klamath River Basin Study utilizes an ensemble of climate projections based on both CMIP3 and CMIP5.

HDe Climate Scenarios

Ensemble hybrid delta climate scenarios representing five quadrants of precipitation and temperature change (warm wet, warm dry, central tendency, hot dry, hot wet) are used to encompass a range of possible climate futures for two future time horizons, the 2030s and the 2070s.

The HDe method involves defining a climate change scenario based on pooled information from a collection of climate projections. Use of a sufficiently large number of projections (commonly called an ensemble) pooled together reduces the signal of internal climate variability (which is inherent in each single projection), which may be misinterpreted as climate change. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios. These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT).

Historical precipitation and temperature are mapped, using a quantile mapping technique, onto the bias corrected GCM data to produce a set of transformed observations reflecting future conditions. The entire observed time series of temperature and precipitation at each hydrologic model grid cell is perturbed in this manner, resulting in a new time series that has the statistics of the bias corrected GCM data for the future period, but preserves the time series and spatial characteristics of the gridded temperature and precipitation observations.

The HDe scenarios for the Klamath River Basin Study culminate in a total of 20 scenarios, including two future time horizons (2030s and 2070s), five quadrants of projected change (HW, HD, CT, WW, and WD), and two sets of projections (CMIP3 and CMIP5). Each of these scenarios resemble the historical inputs of daily precipitation and temperature (minimum and maximum) to the VIC surface water hydrologic model in format and period of record because they are all perturbations of historical time series. Windspeed, the remaining required input to the VIC model, was assumed not to change between historical and future time periods. This assumption is in part due to the coarse resolution of historical windspeed data used in the Maurer et al. (2002) historical meteorological dataset

and the associated high level of uncertainty in the data. However, to provide some context, Pryor et al. (2012) found some evidence of lower intense windspeeds in the western U.S. for the 2041–2062 period compared with 1979–2000 from regional climate model simulations.

Figure 3-19 summarizes projected changes in precipitation (a) and temperature (b) by month according to the five HDe climate scenarios for each time period in relation to the full suite of CMIP3 and CMIP5 projections by month. This figure illustrates that the derived climate scenarios generally span the range of projected future precipitation and temperature by the greater number of climate projections. However, with respect to precipitation change, it appears the HDe scenarios project a greater tendency toward increased precipitation during summer months (August, in particular) than the raw climate projections indicate. This is likely due to the fact that the HDe projections are based on projected annual changes in precipitation, not seasonal or monthly changes. Projected annual changes in precipitation appear to be influenced more by increases in winter precipitation.

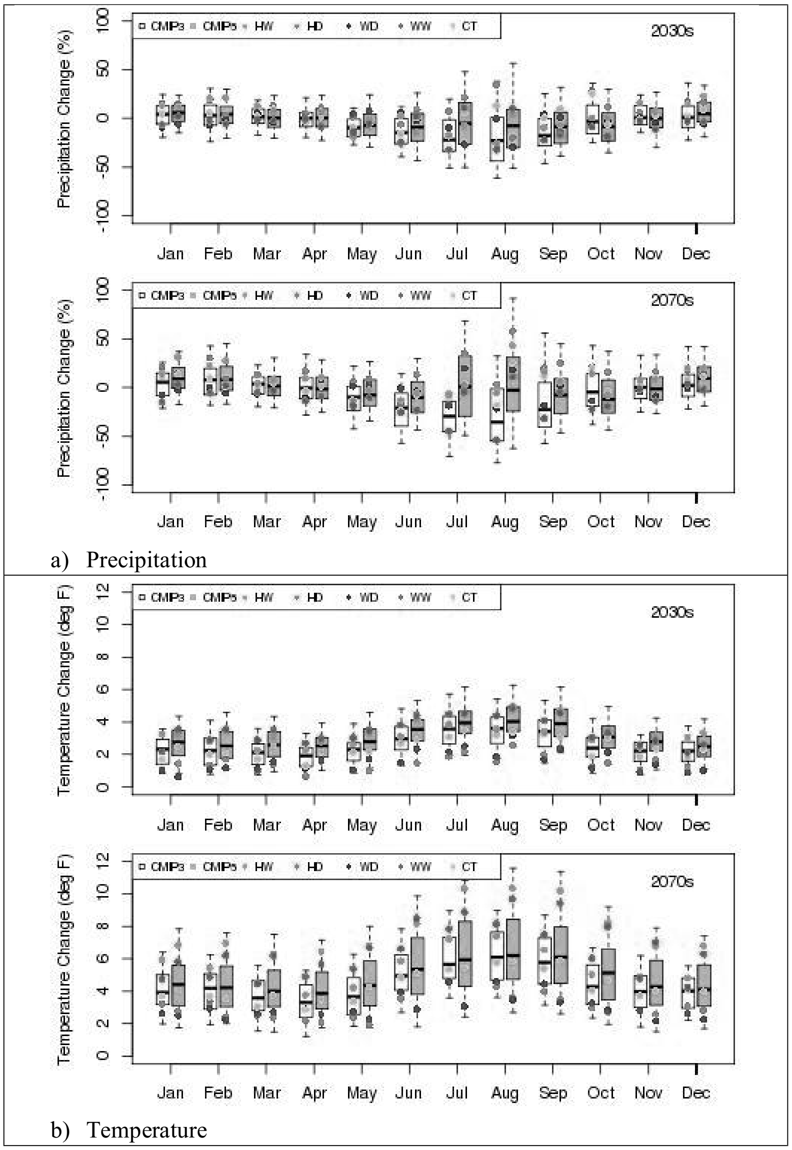


Figure 3-19. Changes in mean monthly precipitation and temperature

HDe scenarios have a number of distinguishing features, with associated strengths and weaknesses. One weakness of this approach is that analysis of climate change impacts is limited to the future time horizons chosen when developing precipitation and temperature change factors. Another weakness is that the scenarios do not incorporate projected changes in drought variability or sequencing of storm events. One key strength of the HDe approach is that the time sequence of projected future storm events matches historical climate data, facilitating direct comparison between the observations and future scenarios. The HDe approach is suitable for water resources planning at both daily and longer time scales, supports analysis of daily hydrologic extremes such as flood and drought intensity, and provides consistency across a range of spatial scales (Hamlet et al., 2010).

3.5.1.3 Deriving Paleo-Conditioned Streamflow Projections

Understanding drought variability is critical to managing water resources across the western U.S. The HDe scenarios described in the previous section may be used as input to surface and groundwater hydrologic models to evaluate changes in the water balance. As mentioned, HDe scenarios are perturbations of the historical record that reflect the statistics of future climate over some chosen time period. As a result, they do not explore the possibility of changes in drought variability (i.e., length or severity of drought periods and wet periods).

Paleo-climate information derived from tree rings or other proxies provides a greater context for sequencing and duration of wet and dry periods than the historical record can provide, often going back hundreds of years. The paleo-conditioned streamflow projections described in this section achieve a blend of projected climate information derived from GCMs and paleo-climate information.

To develop a long-term understanding of drought variability across North America, Cook et al. (2004) developed an extended record of summer time PDSI (Palmer Drought Severity Index) using tree-ring chronologies. This extended PDSI record for North America is available as a gridded (2.5 degrees latitude by 2.5 degrees longitude) timeseries, nearly 200 miles on a side, that dates back nearly 2000 years in some locations. Availability of this extended gridded PDSI record provides an opportunity to analyze regional drought and wet spell characteristics.

For the Klamath River Basin Study water supply assessment, a representative grid location (see Figure 3-20) from the extended gridded PDSI archive was used to analyze long-term wet and dry spells in the Klamath River Basin. Adjacent grid locations provided similar results. The specific location of the PDSI grid used has a center with latitude 42.5 degrees N and longitude 120.0 degrees W., shown by a green triangle in Figure 3-20. The PDSI time-series used from this grid extended from 1400 through 1999.

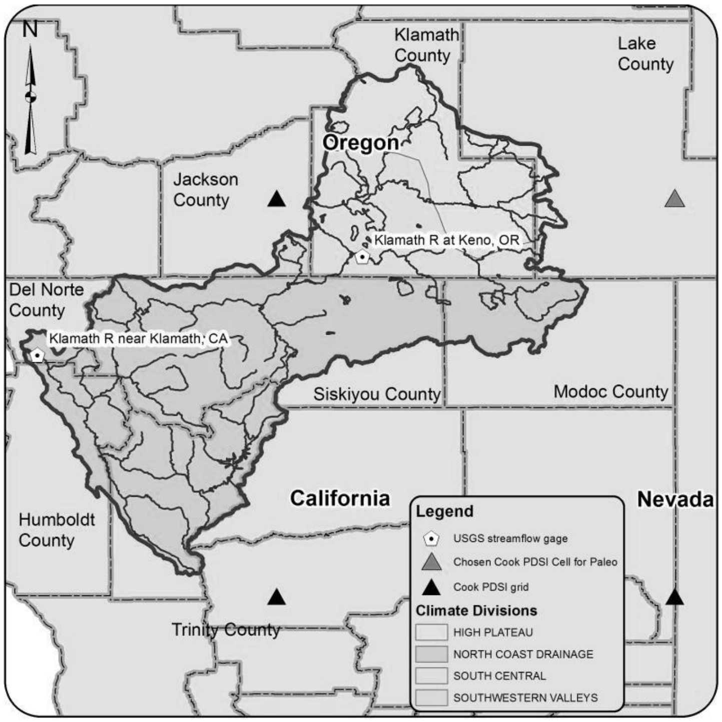


Figure 3-20. Overview map of the Klamath River Basin with Cook PDSI grid and two USGS streamflow gages used in the analysis of paleo-hydrology: Klamath River near Klamath, CA and at Keno, OR

To understand the time-varying nature of wet and dry spells, the PDSI index can be used to determine the probability of regional hydrology shifting from one state to another. In this study, the Klamath River Basin was defined to be either in dry state when the summer time PDSI value in a given year was less than 0 (negative PDSI corresponds to dry conditions), or in a wet state when PDSI was greater than 0 (positive PDSI values correspond to wet conditions). Based on the defined states, probabilities may be derived for the likelihood of transitioning from one state to another. Flow magnitudes can be assigned based on the probabilities, which allows for evaluation of historical streamflow over the instrumental record and projected streamflow compared with the paleo period.

The results for the Klamath River indicate that paleo-conditioned historical simulations show reduced lengths and volumes of wet periods. Results also show droughts of reduced length and deficit, demonstrating that just changing the ordering of flows over the historical period results in periods of both reduced droughts and surpluses. Furthermore, the wet period volumes could be quite a bit lower than what has been historically available, according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than is shown in the recent instrumental record.

> **Paleo-Conditioned Streamflow Projections**
>
> Wet period volumes could be quite a bit lower than what has been historically available according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than what is shown in the recent instrumental record.

Paleo-conditioned streamflow projections are not carried throughout the Klamath River Basin Study water supply assessment and subsequent phases of the Basin Study for two primary reasons. First, analysis of paleo-conditioned streamflow, including historical and HDe scenarios, suggests that periods of drought and surplus over the paleo record are within the range of variability experienced for the historical 1950–1999 period. Thus, including paleo-conditioned projections of streamflow, and potentially other variables, would be computationally time-intensive yet would not yield additional information. Second, because the Klamath River Basin lacks an integrated surface water – groundwater model, there would be inconsistencies in data linkages between models that make use of paleo-conditioned projections infeasible. For example, the groundwater models rely on inputs of climate, recharge, and streamflow, yet paleo-conditioned projections of climate and water balance variables do not exist to correspond with the paleo-conditioned streamflow projections. Paleo-conditioned streamflow projections may provide a greater context for future water supply projections, but are not directly used in further analysis.

3.5.1.4 Surface Water Hydrology

Assessment of climate change impacts on surface water supply was conducted using HDe (ensemble informed hybrid delta) scenarios and was informed by paleo-conditioned streamflow projections. The overall approach is described below and is illustrated in an overview diagram in Figure 3-21.

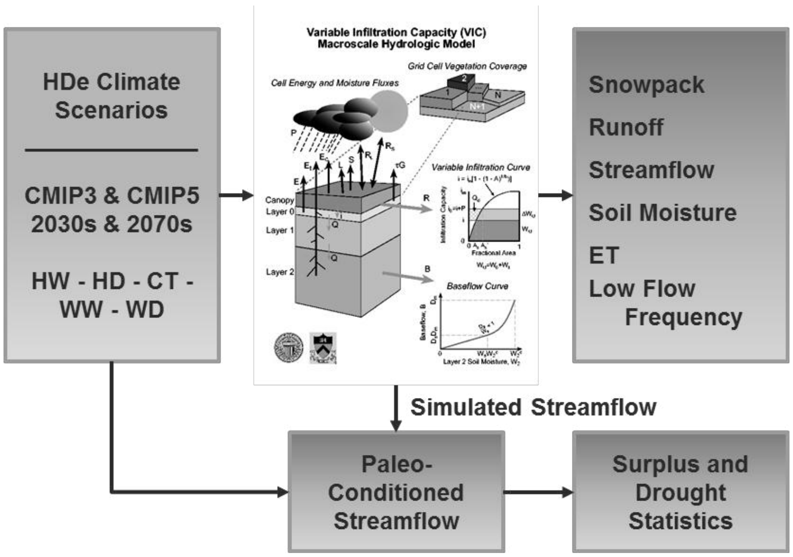


Figure 3-21. Approach for assessment of projected surface water supplies

HDe scenarios may be directly used by the VIC model to generate associated projections of snowpack, runoff, and other elements of the water balance. In evaluating the implications of climate change, the water supply assessment first provides comparisons of results based on CMIP3 and CMIP5 projections with respect to mean annual precipitation and temperature, April 1 SWE, and mean annual runoff.

Following the comparison of CMIP3 and CMIP5 results, the assessment discusses projected changes in seasonal precipitation and temperature, snowpack on April 1, mean annual runoff, spring runoff, June 1 soil moisture, mean annual ET, mean monthly streamflow at select sites, annual runoff timing, and changes in the 7 day low flow with 10 year recurrence interval (also called 7Q10). This part of the assessment focuses on results using CMIP5 projections (unless otherwise noted) for the two future time horizons (2030s and 2070s); however, figures based on CMIP3 projections, corresponding to those presented in the water supply assessment, are presented and briefly discussed in Appendix B, Supplemental Information for Assessment of Water Supply.

Drought and surplus statistics are evaluated based on the developed paleo-conditioned streamflow traces. Paleo-conditioned streamflow relies on projected natural streamflow output from the VIC model as well as statistics developed from the analysis of the paleo-record. Projected natural streamflows from the VIC model are resampled 1,000 times for each of the five HDe climate change scenarios, future time horizons, and projection types (CMIP3 and CMIP5) to develop statistics of projected surplus and drought volumes and lengths.

3.5.1.5 Groundwater Hydrology

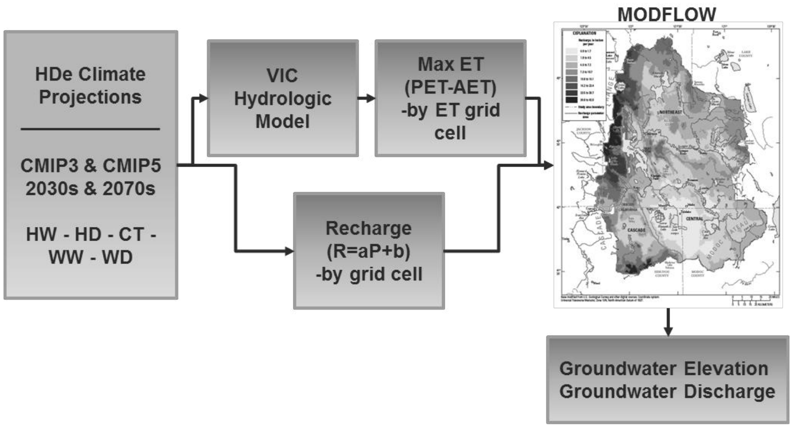
This section describes the approaches for utilizing climate change scenarios to evaluate projected changes in groundwater recharge, discharge, and elevations in three groundwater basins of the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys.

Upper Klamath Basin

The effects of projected climate on groundwater in the Upper Klamath Basin were analyzed using the existing MODFLOW finite-difference groundwater model developed by Gannett et al. (2012). For this study, the model was driven by HDe climate scenarios and surface water hydrologic projections, and results were compared with the historical simulation (presented and summarized in Section 3.4.3, Present Availability and Historical Trends – Upper Klamath Basin) to evaluate results due to changes in climate alone, excluding any impact due to changes in groundwater demand (i.e., pumping). Paleo-conditioned streamflow projections were not taken through the Upper Klamath Basin groundwater impacts analysis because stream stages are held constant in the MODFLOW simulations and Gannett et al. (2012) determined that streams generally have very little net exchange with the groundwater system. The avenues for incorporation of projected surface water inputs into the MODFLOW model are listed below, and they do not have associated paleo-conditioned projections.

1. Projected maximum ET for each of the five HDe climate change scenarios, where maximum ET is represented as PET less actual ET as computed from VIC surface water hydrology model output
2. Projected groundwater recharge for each of three recharge zones for each of the five HDe climate change scenarios

The methodology for developing each type of projected MODFLOW input is described briefly below and illustrated in an overview diagram in Figure 3-22.



** Paleo-Conditioned Streamflow to provide context for projected surplus and drought spells*

Figure 3-22. Approach for assessment of projected groundwater supplies in the Upper Klamath Basin

Maximum Evapotranspiration Rate

Evapotranspiration is modeled in the Upper Klamath Basin MODFLOW model (Gannett et al., 2012) using the EVT, or evapotranspiration package. One of the principal input parameters is the maximum ET rate associated with groundwater. Gannett et al. (2012) computed this parameter based on output from the PRMS surface water hydrology model. Specifically, this parameter is computed as the difference between PET and actual ET. This difference represents the amount of potential demand that could be supplied by groundwater and is not supplied by precipitation.

In this study, the VIC model was used to generate meteorological inputs for future MODFLOW simulations. The VIC model was chosen, as opposed to PRMS, because it is available for the entire Klamath River Basin, is widely used for studies of climate change impacts, and was used in the hydrologic modeling and development of hydrologic projections as part of Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). Maximum ET was computed on a quarterly (seasonal) basis from VIC simulations for the five HDe climate change scenarios. Quarterly maximum ET computed from VIC simulations (at 1/8th degree spatial resolution) was compared with historical maximum ET used in the historical MODFLOW simulation, aggregated to VIC's spatial resolution. Quarterly (stress period) change factors were developed at the VIC model spatial resolution and factors were applied to historical maximum ET from MODFLOW for each MODFLOW cell within a VIC grid cell. The reason for using change factors and not directly applying projected maximum ET from the VIC model is

to avoid introducing bias due to the differing model constructs (i.e., PRMS generated historical maximum ET while VIC generated projected maximum ET).

Groundwater Recharge

The Gannett et al. (2012) historical groundwater simulation uses as input historical groundwater recharge computed by the PRMS model. Because the VIC model was used to generate inputs for future projection simulations, and because historical simulated recharge from VIC may be quite different from recharge used in the historical MODFLOW simulation (derived from the PRMS hydrologic model), a relationship was developed between historical annual precipitation (gridded dataset developed by Maurer et al. [2002] was used in development of surface water hydrology for this study as well as future climate scenarios) and historical annual recharge.

Although alternate relationships were explored in this study, a linear relationship between precipitation and recharge appeared to best represent the data. Such a relationship was developed using annual recharge and precipitation (at the spatial resolution of the VIC model), aggregated by recharge zone. Using the developed relationships between annual recharge and precipitation (by recharge zone) based on historical data, the same relationship was applied to each of the five HDe climate change scenarios of precipitation for two future time periods (2030s and 2070s) and for CMIP3 and CMIP5 projections. As a result, corresponding projections of recharge were developed at the VIC model resolution. These projections were used to generate annual change factors (based on ratios between projected recharge and MODFLOW historical), which were then applied to historical recharge uniformly over all MODFLOW grid cells within a corresponding VIC model grid cell.

Caveats

It should be noted that the described approach for developing projected surface water inputs to the Upper Klamath Basin MODFLOW model may introduce errors in the groundwater balance due to inconsistently developed inputs. For example, recharge and maximum ET projections were developed using established relationships between projections based on HDe scenarios and historical values used in MODFLOW historical simulations. Hence, they were not developed via an integrated surface water model. Despite the use of potentially inconsistent methodologies, this approach provides the best available estimates of projected surface inputs to the groundwater system.

Scott and Shasta Valleys

Projections of future groundwater elevation may be computed for the Scott and Shasta Valleys using the groundwater screening tools developed and described in Section 3.4, Historical Groundwater Availability. Similar to the Upper Klamath Basin, perturbed historical inputs representing projected conditions were used by the models to generate projections of groundwater elevation. Future projections were incorporated for climate and water balance input terms, as well as municipal, domestic, and industrial demand with respect to projected population.

Agricultural demand was left unchanged for the water supply assessment in order to focus on the impacts of climate change on groundwater elevation, and not changes in agricultural demand. Variations in historical agricultural demand are incorporated into historical groundwater elevations used to develop relationships in the computation of groundwater response. However, projected changes in temperature and precipitation will affect agricultural demand, which may markedly affect groundwater levels beyond what was experienced historically. In the discussions of climate change impacts on water demand in the watershed and associated risks and system reliability (Chapters 4 and 5 of this Klamath River Basin Study report, respectively), we address projected changes in agricultural demand and how the watershed may be impacted by the compounded stresses associated with climate change (with and without management adaptations).

Specific projected inputs to the groundwater screening tools for the Scott and Shasta Valleys are further described below. An overview diagram illustrating how projected inputs are incorporated into the groundwater screening tools is provided in Figure 3-23.

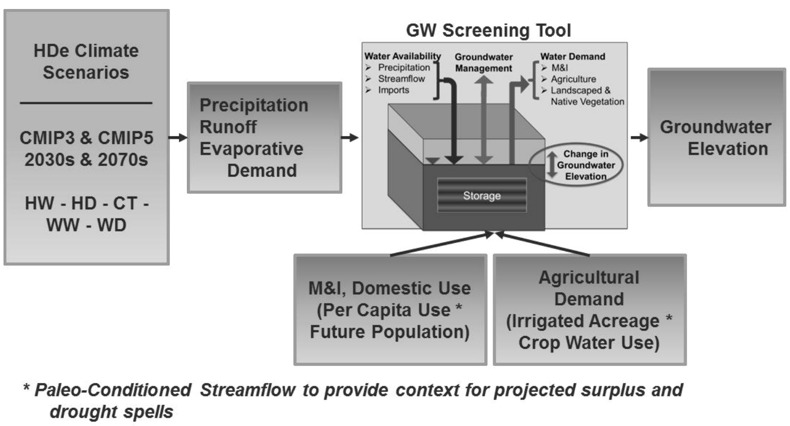


Figure 3-23. Approach for assessment of projected groundwater supplies in the Scott and Shasta Valleys

Future projections of monthly mean precipitation and daily mean temperature (surrogate for evaporative demand) computed over the groundwater basins were input to the groundwater screening tools for each basin. These climate scenarios were based on the five HDe climate change scenarios for two future time horizons (2030s and 2070s) as well as for projections based on both CMIP3 and CMIP5. Similar projections of mean monthly runoff over each of the groundwater basins were also input to the models.

It should be noted that the approaches described above for developing projected surface water inputs to the Scott and Shasta Valley groundwater screening tools (including precipitation, temperature, and runoff) are compatible. These inputs rely on HDe climate scenarios themselves (in the case of precipitation and temperature) or outputs generated by the VIC model (runoff) whose simulations rely on HDe climate scenarios.

Municipal, industrial, and domestic water demand, which was computed based on the product of per capita water use and population, was perturbed according to projected population growth. Per capita use was assumed to remain constant. Projected population for each of the two future time horizons (2030s and 2070s) was computed by assuming a percent increase in population equal to the percent change between 1990 and 2000, which was documented by the 2000 Census.[5] For the Scott Valley this was +1.93 percent, while for the Shasta Valley it was +2.01 percent over ten years. The mean of projected population 2020–2050 was used to represent 2030s population, while the mean of projected population 2060–2080 was used to represent 2070s population. Additional scenarios of population growth were not considered as part of the water supply assessment; however, additional scenarios may be considered in subsequent stages of the Klamath River Basin Study as part of the analysis of management alternatives and/or adaptation strategies.

As previously mentioned, agricultural water demands were not modified as part of the evaluation of climate change impacts on groundwater elevations in the Scott and Shasta Valleys. The primary reason changes in agricultural demand were not considered here is that detailed analysis of the implications of projected agricultural demand is part of the assessment of current and future water demands in Chapter 4.

3.6 Comparison between CMIP3 and CMIP5

Projections of climate as well as surface water and groundwater hydrologic variables were summarized using both CMIP3- and CMIP5-based projections to understand whether these projections provide a similar view of future conditions. Few studies exist to provide guidance on whether the more recent CMIP5 projections ought to supersede those from CMIP3, whether they are similar enough that one or the other may be used, or whether they ought to be used collectively in impacts assessments. The intent of the Klamath River Basin Study water supply assessment is not to provide such guidance, but instead to evaluate the impacts of climate change using both sources of projections to provide the most comprehensive understanding possible of projected changes in water supply in the watershed.

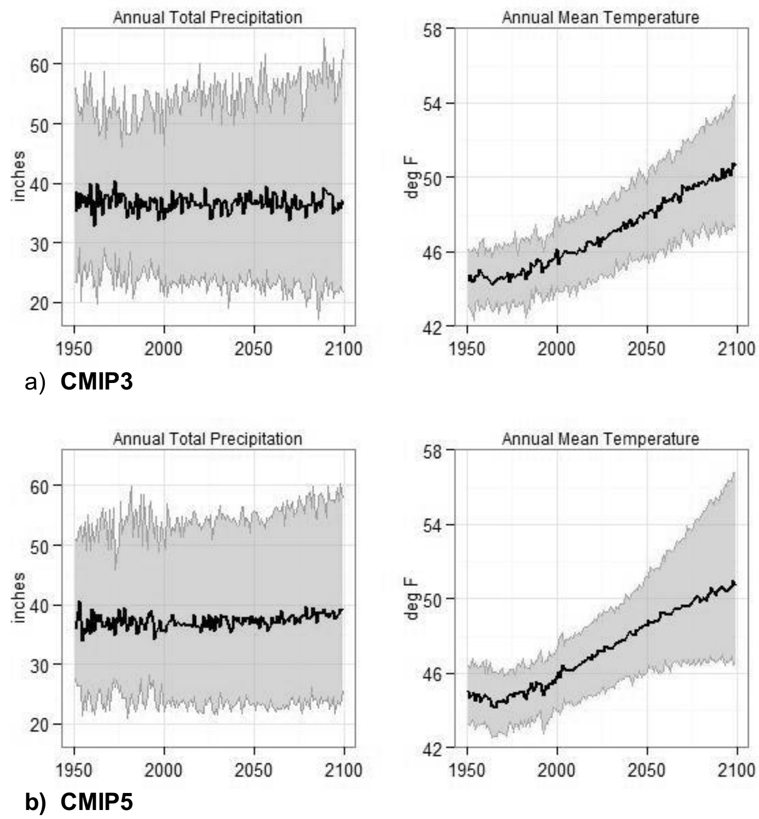
[5] http://www.ncdc.noaa.gov/climate/research/population/

3.6.1 Climate

The basis for the five HDe climate change scenarios of precipitation and temperature (minimum and maximum) used throughout the Klamath River Basin water supply assessment is a suite of monthly statistically downscaled GCM simulations, based on CMIP3 and CMIP5 projections. As described in detail in Section 3.5.1.1, Climate Projections, HDe scenarios are generated by computing change factors between designated future time horizons (in this case the 2030s and 2070s) and a designated historical period (in this case 1970–1999).

Figure 3-24 illustrates the envelopes of projected mean annual precipitation and temperature as they evolve through time (i.e., light red on the top panel for temperature and light blue on the bottom panel for precipitation). All projections show that the region will become warmer during the 21st century, with greater uncertainty in annual temperature farther into the future as shown by the widening swath of projections. Annual precipitation in the Klamath River Basin is projected to increase slightly through time. However, it should be noted that this slight projected increase (both for CMIP3 and CMIP5 projections) is within the range of historical variability in precipitation from year to year. In contrast, for temperature, the median projection shows that temperatures will exceed the range of historical year to year variability by about 2050.

A comparison of CMIP3 and CMIP5 projections shows that trajectories through time appear similar; however, the range of projected precipitation is similar between the two types of projections, while projected temperature appears greater with CMIP5 projections. The larger projected range in projected temperature is likely due to the consideration of the full range of emissions scenarios for both CMIP3- and CMIP5-based projections. As shown in Figure 3-24, the range of projected global warming is greater for CMIP5 scenarios than for CMIP3.



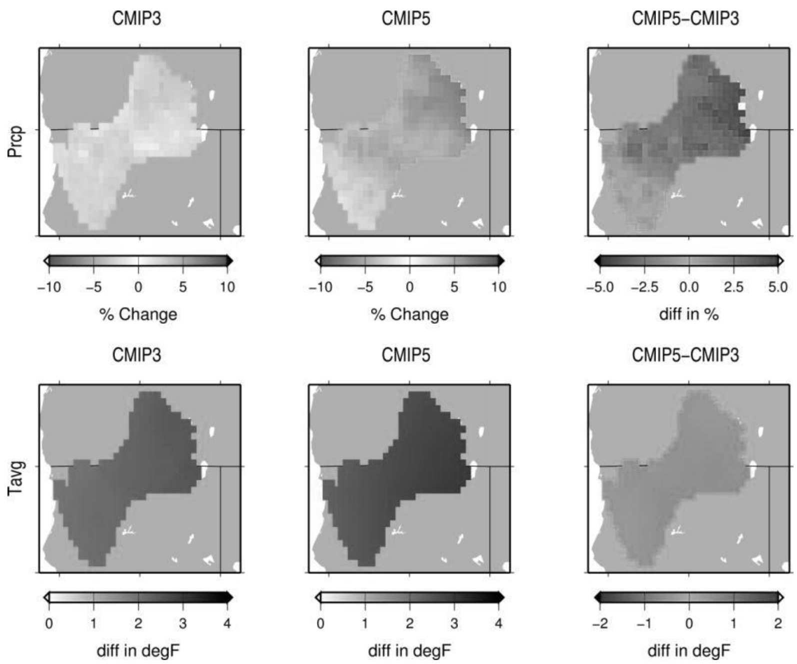
Note: The top row (a) and bottom row (b) illustrate the range of CMIP3 projections and CMIP5 projections, respectively. The black line in each panel shows the median of annual projections, while the colored band represents the range of all GCM projections (112 for CMIP3 and 234 for CMIP5).

Figure 3-24. Summary of statistically downscaled GCM projections of mean annual precipitation and temperature from 1950 to 2100

Figure 3-25 shows projected changes in mean annual precipitation (in percent) and average temperature (in degrees F) for the 2030s, compared with the historical baseline (1950–1999), using both CMIP3- and CMIP5-based HDe scenarios, while Figure 3-26 shows similar projections for the 2070s. It should be noted that these projections do not reflect information from the paleo record, as paleo-conditioned projections only correspond with streamflow. The projections shown in the figures represent the central tendency derived using the HDe approach. Each figure shows projections based on CMIP3 in the left panel,

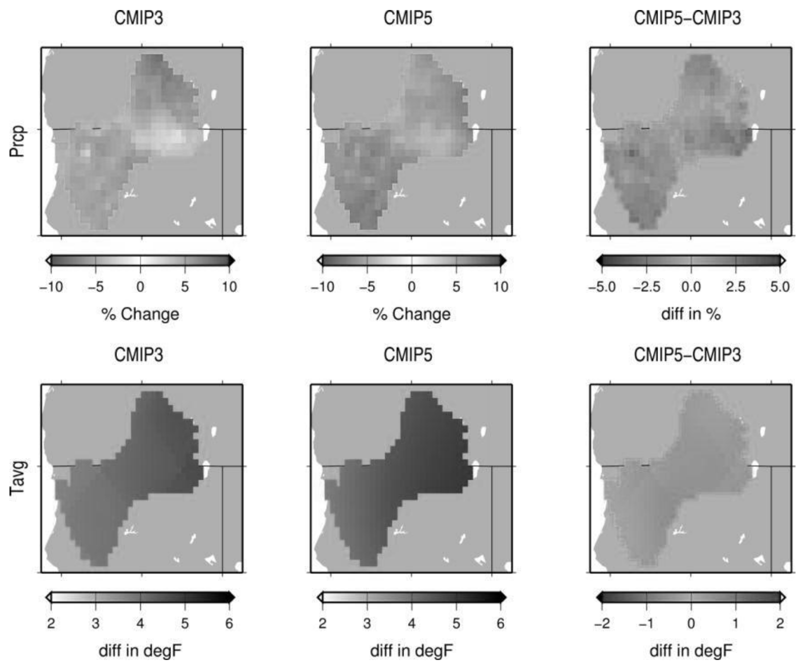
projections based on CMIP5 in the middle panel, and the difference between CMIP5 and CMIP3 in the right panel.

Projected changes in precipitation and temperature are positive for both CMIP3 and CMIP5 for the 2030s and 2070s. As can be seen in Table 3-5, which summarizes spatially averaged projected changes for both time horizons and over three dominant Klamath River Basin climate divisions as well as the basin as a whole, there are notable differences in the magnitude of projected change.



Notes:
1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

Figure 3-25. Comparison of percent change (2030s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5



Notes:
1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

Figure 3-26. Comparison of percent change (2070s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5

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For the 2030s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the North Coast Drainage, which is located at the California portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 4.1 percent increase in mean annual precipitation, while CMIP3-based scenarios indicate a 2.4 percent increase by the 2030s. CMIP5-based scenarios are noticeably wetter than CMIP3 in the eastern portions of the High Plateau and South Central climate divisions. However, CMIP5-based scenarios are noticeably drier in the southernmost portion of the watershed, as previously mentioned. With respect to mean annual average temperature for the 2030s, CMIP5 projections indicate a greater increase in temperature than CMIP3 for all spatial domains considered (see Figure 3-2), although the projections are not substantially different. Projected temperatures basin-wide for the 2030s central

tendency show an increase of 2.2 degrees F for CMIP3 and 2.7 degrees F for CMIP5.

For the 2070s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the High Plateau, which is located at the northernmost portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 6.1 percent increase in mean annual precipitation, while CMIP3 projections indicate a 5.2 percent increase by the 2070s. With respect to mean annual average temperature for the 2070s, CMIP5 projections indicate a greater increase in temperature than CMIP3 projections for all spatial domains, which is similar to results for the 2030s. Projected temperatures basin-wide for the 2070s central tendency indicate an increase of 4.2 degrees F for CMIP3 and 4.5 degrees F for CMIP5.

Although the magnitude differences are quite similar between CMIP3 and CMIP5 for precipitation and temperature for each future time horizon (central tendency), the spatial differences between CMIP3 and CMIP5 are interesting (see the right panels of Figures 3-25 and 3-26). For the 2030s, CMIP3 projections show less increase in precipitation that CMIP5 in the lowermost portion of the Klamath River Basin, while also showing a larger increase in the easternmost portion of the basin. For the 2070s, CMIP3 projections show less increase in precipitation in the Oregon portion of the basin than CMIP5 projections, while in most other parts of the basin CMIP5 projections show greater increase. The spatial differences between CMIP3- and CMIP5-based scenarios may be due to internal variability in the model simulations, and therefore the spatial patterns should be viewed collectively as potential future conditions.

CMIP3 and CMIP5 Comparison – Precipitation and Temperature

Ranges of projected precipitation appear similar while ranges of temperature appear greater with CMIP5 than with CMIP3 scenarios. Spatial differences between CMIP3 and CMIP5 scenarios may be due to internal variability in the model simulations and HDe scenario development. By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

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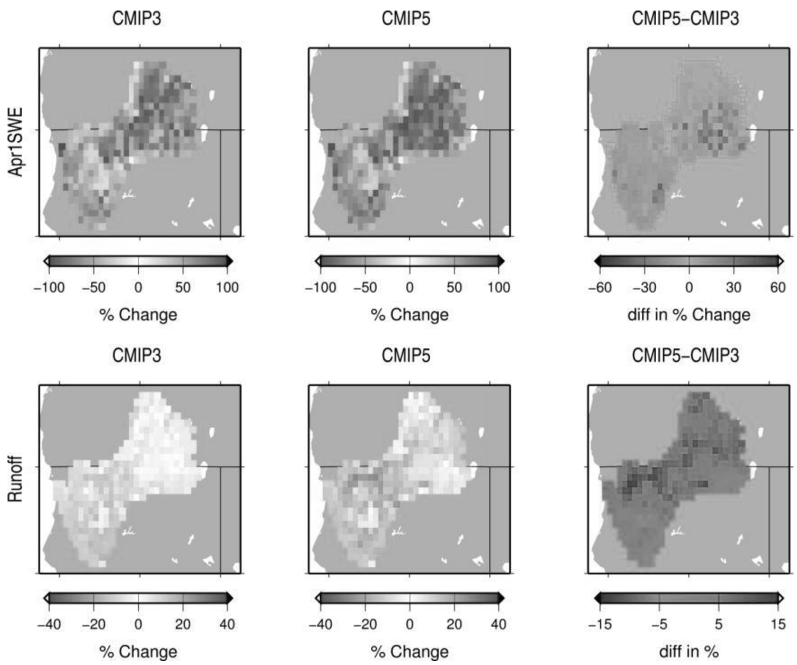
Table 3-5. Summary of projected changes in mean annual precipitation and average temperature for the 2070s, compared with the historical baseline

(1950–1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions

Climate Division	Basinwide	North Coast Drainage	South Central	High Plateau
2030s				
Prcp, CMIP3	+2.4 %	+2.3 %	+2.4 %	+2.7 %
Prcp, CMIP5	+4.1 %	+3.6 %	+5.4 %	+5.8 %
Tavg, CMIP3	+2.2 degF	+2.2 degF	+2.3 degF	+2.4 degF
Tavg, CMIP5	+2.7 degF	+2.6 degF	+2.8 degF	+2.8 degF
2070s				
Prcp, CMIP3	+5.2 %	+5.0 %	+5.1 %	+6.4 %
Prcp, CMIP5	+6.1 %	+6.3 %	+5.3 %	+5.7 %
Tavg, CMIP3	+4.2 degF	+4.1 degF	+4.3 degF	+4.4 degF
Tavg, CMIP5	+4.5 degF	+4.4 degF	+4.7 degF	+4.7 degF

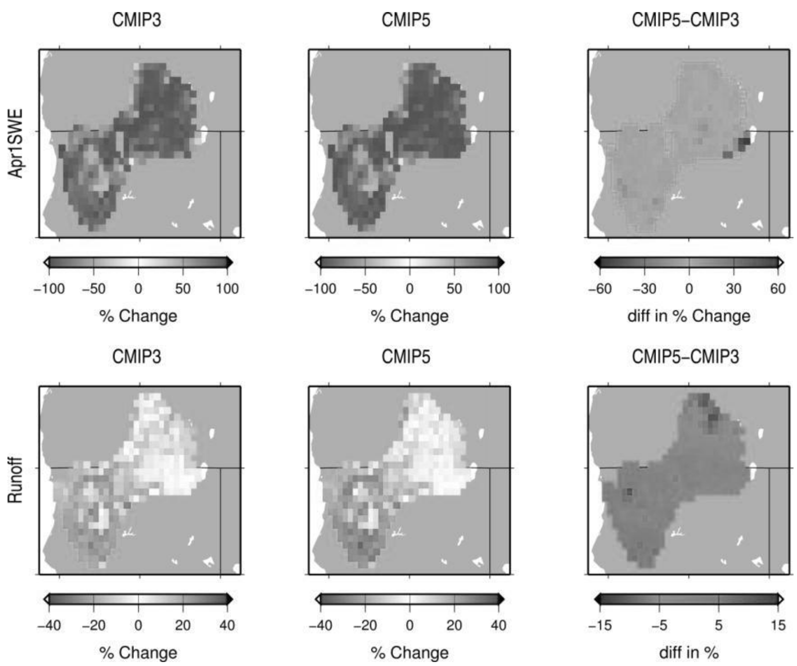
3.6.2 Water Balance

Comparisons of CMIP3 and CMIP5 projections of April 1 SWE and mean annual runoff, both calculated using the VIC model, are illustrated in Figure 3-27 for the 2030s and Figure 3-28 for the 2070s and summarized in Table 3-6. Projections of snowpack on April 1 are presented, in part, because this is a common measure often used in climate change impact studies across the western U.S., but also because historical snowpack is at, or just past, its peak in early April and this measure is often used by water managers as a measure of spring and summer water supply. For the 2070s, CMIP3- and CMIP5-based projections of April 1 SWE show a similar magnitude of change and slight spatial differences (refer to Figure 3-28, upper left and upper central panels). The water balance terms are influenced by changes in precipitation and temperature across the landscape. Although both CMIP3 and CMIP5 projections indicate declines in April 1 SWE by roughly 30 to 40 percent by the 2030s and 60 percent by the 2070s for the central tendency, despite projected increases in annual runoff (see Table 3-5 for computed percent change over the basin and three dominant climate divisions).



Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

Figure 3-27. Comparison of percent change (2030s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios based on CMIP3 and CMIP5



Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

Figure 3-28. Comparison of percent change (2070s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios, based on CMIP3 and CMIP5

For both future time horizons, greater decreases in snowpack are projected for lower elevation regions while mountainous parts of the basin, namely the Cascades and Trinity Alps, show smaller projected decreases in April 1 SWE. Further, for the VIC model pixel that contains Mount Shasta (refer to the white square in the central area of the upper left and upper central panels of Figure 3-27 and Figure 3-28), snowpack is not projected to change substantially, likely due to the combined effects of its relatively high elevation, projected increases in precipitation, and projected increases in temperature.

The upper right panels of Figure 3-27 and Figure 3-28 show the differences in April 1 SWE between CMIP3 and CMIP5 projections. Although differences for the 2030s and 2070s central tendency are small, the CMIP3 projection indicates a larger decrease in snowpack than CMIP5 in parts of the Upper Klamath Basin for the 2030s and the easternmost portion of the basin in California for the 2070s. Smaller differences in April 1 SWE are projected for the 2070s. Mean percent

change in April 1 SWE across the Klamath River Basin is -33.8 percent for the 2030s and -58.2 percent for the 2070s.

Table 3-6. Summary of projected changes in April 1 SWE and annual runoff for the 2030s compared with the historical baseline (1950-1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions

Climate Division	Basinwide	High Plateau	South Central	North Coast Drainage
2030s				
Apr1 SWE, CMIP3	-33.8 %	-38.9 %	-31.0 %	-32.5 %
Apr1 SWE, CMIP5	-39.8 %	-41.4 %	-35.4 %	-39.8 %
Ann Runoff, CMIP3	+7.3 %	+1.4 %	-0.6 %	+8.8%
Ann Runoff, CMIP5	+11.6%	+3.4 %	+4.6 %	+12.9 %
2070s				
Apr1 SWE, CMIP3	-58.2 %	-61.9 %	-54.7 %	-57.3 %
Apr1 SWE, CMIP5	-62.0 %	-65.6 %	-58.8 %	-61.1 %
Ann Runoff, CMIP3	+13.9 %	+0.1 %	-0.5 %	+16.4 %
Ann Runoff, CMIP5	+15.3 %	-5.1 %	-2.5 %	+18.7 %

According to projections based on both CMIP3 and CMIP5 for the 2030s and 2070s, mean annual runoff is projected to increase in the Lower Klamath Basin while changes in the Upper Klamath Basin vary both in magnitude and direction and between CMIP3 and CMIP5 (refer to lower panels of Figure 3-27 and Figure 3-28). Projected changes in runoff based on climate division show increases in the North Coast Drainage on the order of 16 or 19 percent (for CMIP3 and CMIP5, respectively) for the 2070s central tendency and decreases across the South Central climate division on the order of 1 to 3 percent (for CMIP3 and CMIP5, respectively). Across the High Plateau (the region upstream and to the east of Upper Klamath Lake; refer to Figure 3-2), projections are mixed, with CMIP3-based projections indicating a slight increase in mean annual runoff and CMIP5-based projections indicating a decrease in mean annual runoff for the 2070s. The lower right panels of Figure 3-27 and Figure 3-28 illustrate the spatial difference between CMIP3 and CMIP5 for the 2030s and 2070s, respectively. For the 2030s, CMIP5 projections indicate greater changes in runoff over the mainstem Klamath River area than CMIP3, yet smaller changes in runoff over the higher elevation regions of the Trinity River basin and Tule Lake area. For the 2070s, CMIP5 projects lower runoff change than

CMIP3 and CMIP5 Comparison – Water Balance

CMIP3 and CMIP5 water balance projections are largely consistent, indicating decreases in April 1 SWE on the order of 34-40 percent for the 2030s and close to 60 percent for the 2070s, and increases in annual runoff of 7-12 percent for the 2030s and 14-15 percent for the 2070s.

CMIP3 in the Upper Klamath Basin and lower runoff change than CMIP3 in the Lower Klamath Basin.

The differences between CMIP3 and CMIP5 projections for the 2070s central tendency in projected precipitation, temperature, snowpack, and runoff show great similarities in the central tendency scenario for the Klamath River Basin as a whole. However, there are notable differences in that CMIP5 projections tend to be wetter and warmer over the Klamath River Basin than those from CMIP3. Also, there are notable spatial differences that are important to consider when relying on projections from either CMIP3 or CMIP5 (but not both) for water management decision-making.

3.7 Future Availability

Projected availability of surface water and groundwater in the Klamath River Basin was assessed by evaluating changes in seasonal precipitation and temperature, snowpack, timing and quantity of runoff, soil moisture and ET, low flow frequency, and groundwater recharge and discharge. For the most part, this assessment focuses on projections based on CMIP5; however, corresponding results based on CMIP3 projections were also developed and are included in Appendix B, Supplemental Information for Assessment of Water Supply.

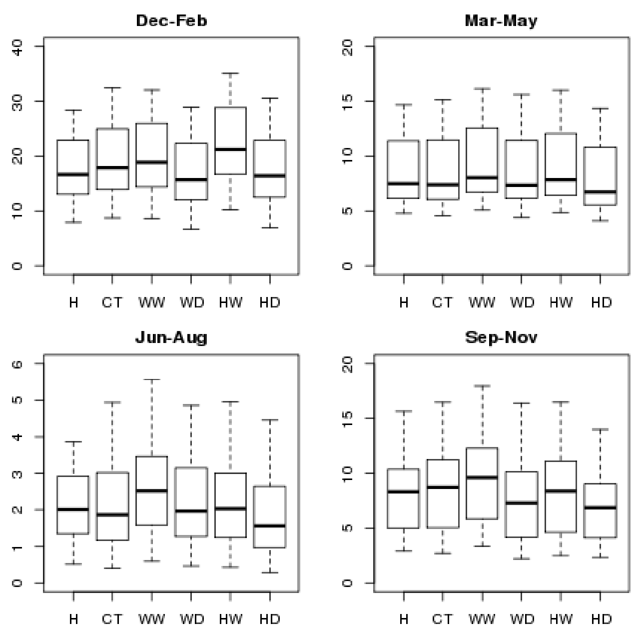
Figure 3-29 illustrates projections of seasonal basin mean precipitation for the 2070s compared with the historical period, based on CMIP5. Each panel includes box plots of historical and projected precipitation, where the boxes represent the 25th, 50th, and 75th percentile values for seasonal precipitation averaged across the Klamath River Basin, and the whiskers represent the 5th and 95th percentile values.

> **Future Availability – Precipitation and Temperature**
>
> Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

In general, the box plots show that the majority of precipitation falls between December and February, an order of magnitude greater than between June and August. In winter (December through February; refer to upper left panel of Figure 3-33), central tendency, WW, and HW scenarios indicate an increase in precipitation, while the WD and HD scenarios indicate decreases in precipitation over this time period. The range between 5th and 95th percentile values across each of the five HDe climate change scenarios appears similar. Projections for the spring period between March and May (upper right panel) and the autumn period between September and November (lower right panel) appear similar to historical conditions, with slight increases for the wetter scenarios (WW and HW) and slight decreases for the drier scenarios (WD and HD). Projections for the summer period (June through August; refer to lower

left panel) show a slight decrease in the median of the central tendency scenarios compared with historical, and decreases in general for the drier scenarios and increases for the wetter scenarios. However, it is notable that the WW scenario indicates a larger increase in summer precipitation than the HW scenario.

It is important to mention that HDe climate change scenarios were developed based on projected changes from multiple GCMs in annual precipitation and temperature across the basin, potentially dampening the signal toward drier summers and wetter winters (as shown in Figure 3-19). Also, the Klamath River Basin water supply assessment does not evaluate projected changes in extreme precipitation events, which are also likely to change as a result of climate change. The focus of this water supply assessment is on the watershed's overall monthly to seasonal water balance, rather than the effects of individual storm events.

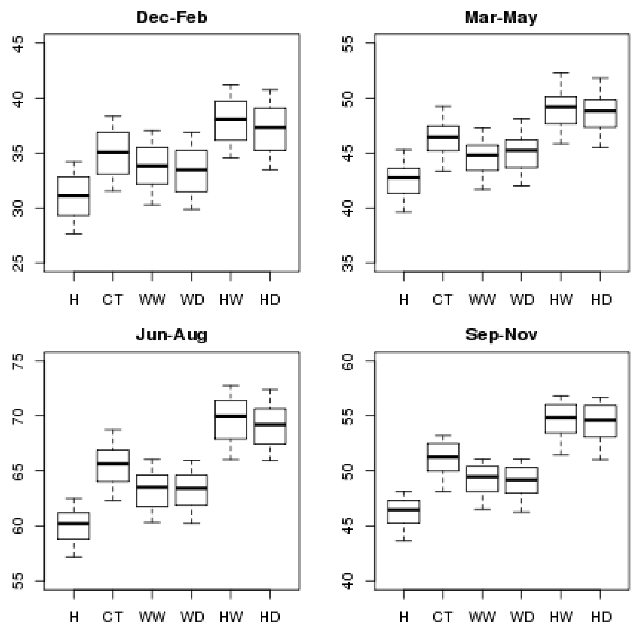


Notes:
1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

Figure 3-29. Seasonal basin mean precipitation (in inches), CMIP5 2070s and historical (1950–1999)

Projections of seasonal temperatures for the 2070s, compared with the historical period (1950–1999) show similar patterns in HDe climate change scenarios across

seasons (refer to Figure 3-30). The hotter HDe scenarios (HW and HD) indicate warmer temperatures relative to the warmer HDe scenarios (WW and WD), compared with historical temperatures. Central tendency scenarios tend to fall in between the warmer and hotter scenarios. What is notable about the seasonal temperature projections is that, for all seasons, the hotter HDe scenarios are mostly outside the range of corresponding historical seasonal temperatures. In summer and fall, even the central tendency HDe scenarios are mostly outside the range of historical temperatures.

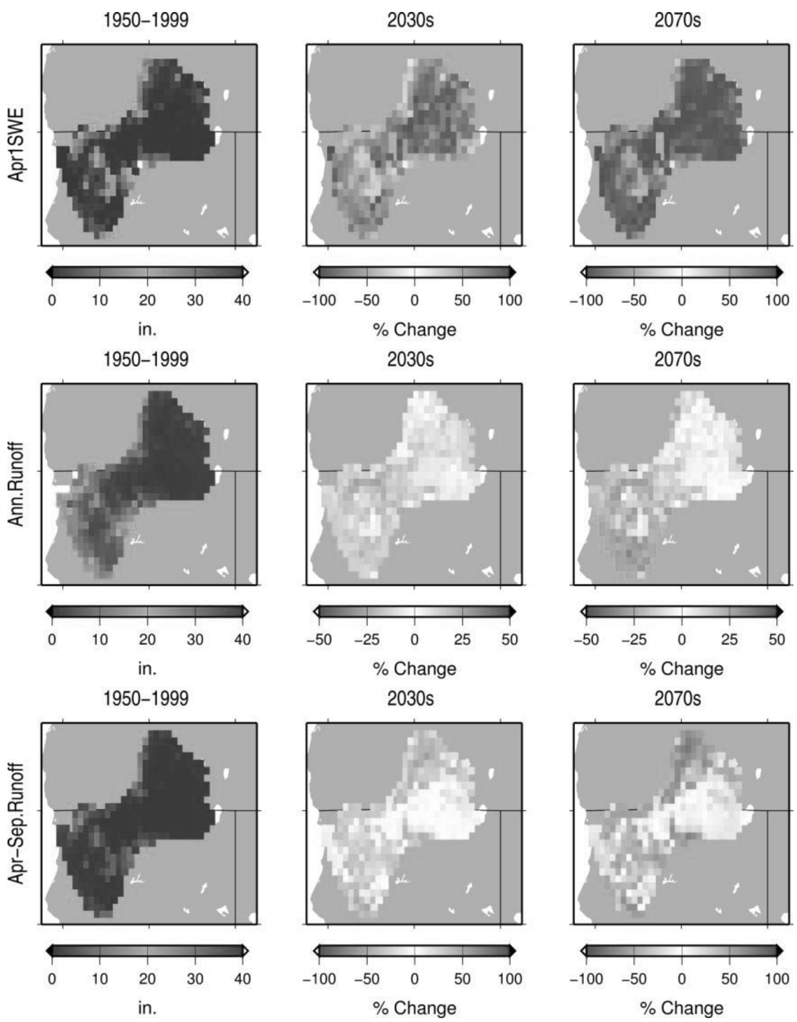


Notes:
1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

Figure 3-30. Seasonal basin mean daily average temperature (in degrees F), CMIP5 2070s and historical (1950–1999)

3.7.1 Changes in Water Balance Terms

This section summarizes projected spatial and basin mean changes in snowpack, annual and spring runoff, soil moisture, and actual ET for the two future time horizons (2030s and 2070s), based on central tendency CMIP5 projections. Figures corresponding to those shown in this section based on CMIP3 projections are included in Appendix B, Supplemental Information for Assessment of Water Supply. It should be noted that paleo-conditioned streamflow projections were not incorporated into the analysis of climate change impacts on surface water balance variables. Figures 3-31 and 3-32 are similar in format in that the left column illustrates mean historical conditions over the period 1950–1999. The middle column illustrates projected percent change for the 2030s future time horizon compared with historical, while the right column illustrates projected percent change for the 2070s future time horizon compared with historical.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from historical values to the 2030s and 2070s, respectively.

Figure 3-31. Comparison of percent change in mean April 1 SWE, mean annual runoff, and mean April-September runoff for the central tendency HDe scenarios based on CMIP5

Mean historical SWE on April 1 (Figure 3-31, top row) falls within the range of little or no snow in the coastal region to almost 40 inches of SWE in the Cascade

Mountains (and even greater snowpack at Mount Shasta). Based on CMIP5 projections, mean percent change in April 1 SWE across the Klamath River Basin is -40 percent for the 2030s and -62percent for the 2070s. Greater decreases are projected for middle to lower elevation parts of the basin. Snowpack at Mount Shasta is expected to exhibit little change (on a percent basis) by the 2030s or 2070s.

Historical mean annual runoff over the 1950–1999 period ranges from a little less than 1 inch in the northeastern part of the basin to more than 40 inches in parts of the coastal region and near Mount Shasta. Basin-wide mean percent change in annual runoff is +12 percent for the 2030s and +15 percent for the 2070s. Most of the Lower Klamath Basin is projected to experience increases in mean annual runoff, while the Cascades region is projected to experience decreases. What is notable with respect to projected changes in mean annual runoff in the Upper Klamath Basin is that projected increases in runoff appear greater for the 2030s than the 2070s. This is likely due to the combined effects of projected increases in precipitation along with projected increases in temperature. For the 2030s, increased precipitation dominates the water balance, resulting in larger increases in annual runoff, while for the 2070s corresponding increases in temperature may cause actual ET to be great enough to show an overall smaller increase in mean annual runoff than for the 2030s.

Future Availability – Water Balance

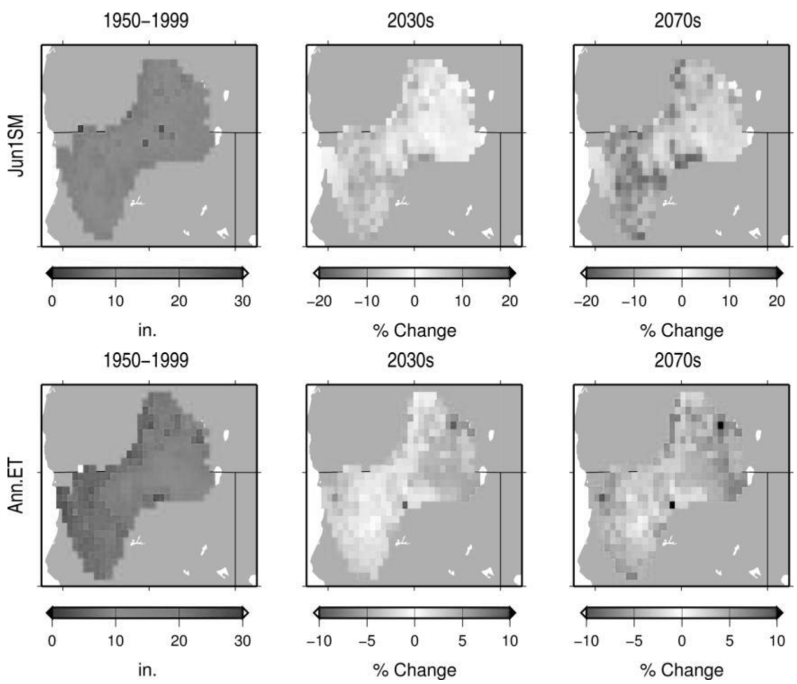
Mean percent change based on CMIP5 central tendency projections includes:

- April 1 SWE: -40 percent (2030s) and -62 percent (2070s)
- Spring (April–September) runoff: -25 percent (2030s) and -40 percent (2070s)
- June 1 soil moisture: -4.9 percent (2030s) and -8.7 percent (2070s)
- Annual ET: +2.6 percent (2030s) and +4.1 percent (2070s)

Historical irrigation season (April through September) runoff over the 1950–1999 period ranges from less than 1 inch to about 30 inches, with higher spring runoff occurring in the mountainous parts of the Klamath River Basin. Mean percent change in spring (April through September) runoff is -25 percent for the 2030s and -40 percent for the 2070s.

Similar to evaluating snowpack at its general peak, projections of soil moisture on June 1 are presented because, in the absence of irrigation or other water management, June is the month of greatest soil moisture throughout the Klamath River Basin. Changes in maximum soil moisture may be of interest to water managers in terms of understanding projected changes in groundwater and soil water availability. Mean historical soil moisture on June 1 over the period 1950–

1999 ranges from less than 1 inch to almost 30 inches, with the greatest soil moisture occurring in mountainous regions with melting snowpack and generally higher precipitation (Figure 3-32). Mean percent change in June 1 soil moisture across the Klamath River Basin is a reduction by 4.9 percent for the 2030s and a reduction by 8.7 percent for the 2070s, compared with the historical period. The pattern of projected change in June 1 soil moisture is similar to that of spring runoff, indicating that projected reductions in soil moisture correspond with reductions in spring runoff. Interestingly, these reductions also correspond with projected increases in mean annual runoff, indicating that there may be a seasonal shift in runoff (discussed in the next section), and therefore June 1 soil moisture.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from 1990s values to the 2030s and 2070s, respectively.

Figure 3-32. Comparison of percent change in mean June 1 soil moisture and mean annual evapotranspiration for the central tendency climate scenario, using groupings of GCMs from CMIP5

Mean historical annual ET over the period 1950–1999 ranges from less than 10 inches to about 33 inches (Figure 3-32). Higher ET values tend to occur in regions with greater water availability (i.e., greater precipitation), like in the Lower Klamath Basin and other mountainous regions. Mean percent change in annual ET basin wide is +2.6 percent for the 2030s and +4.1 percent for the

2070s. Larger percentage increases in ET appear to be projected for parts of the Upper Klamath Basin. However, these results may not reflect relative increases in the amount of water lost to ET, due to the fact that the Upper Klamath Basin generally has lower annual ET.

Figure B-12 in Appendix B, Supplemental Information for Assessment of Water Supply, illustrates projected changes in June 1 soil moisture and mean annual ET for the 2030s and 2070s central tendency, based on the CMIP3 HDe scenarios. Results are similar in spatial patterns of projected change; however, CMIP3-based projections generally indicate smaller projected changes in June 1 soil moisture and annual ET than CMIP5.

3.7.2 Changes in Timing and Quantity of Runoff

This section evaluates projected changes in mean monthly streamflow at selected locations within the Klamath River Basin, the projected shift in timing of mean monthly hydrographs for one example location within the basin, and low flow frequency statistics for select locations. Analyses focus on projected changes for the two future time horizons (2030s and 2070s) based on CMIP5 projections. Figures similar to those presented in this section, but based on CMIP3 projections, are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, the presentation of projected streamflow results at Keno, Oregon (Figure 3-33) includes projections based on both CMIP3 and CMIP5 to allow for direct comparison of mean monthly hydrographs under various types of projections.

Simulated historical and projected mean monthly hydrographs for the Klamath River at Keno, Oregon are presented in Figure 3-33 to illustrate an example of projected changes in overall flow volume and seasonal peak timing of streamflow in the watershed. The top two panels summarize projections based on CMIP3 projections, while the bottom two panels summarize projections based on CMIP5 projections. The mean monthly historical hydrograph is identical in each panel and was computed over water years 1950–1999 (i.e., September 1949–October 1999).

Both CMIP3- and CMIP5-based projections indicate a decrease in spring and summer streamflow for the 2030s and a greater decrease by the 2070s. The wetter of the five HDe climate change scenarios (HW and WW) indicate greater streamflow volume overall, along with higher seasonal peaks. Drier scenarios (HD and WD) indicate reduced streamflow volumes and reduced peaks. Projections for the 2030s (based both on CMIP3 and CMIP5) indicate a shift in seasonal peak timing from approximately zero to one month earlier (a shift from April to March). For the 2070s, projected shifts in seasonal peak timing are zero to two months earlier (a shift from April to as early as February).

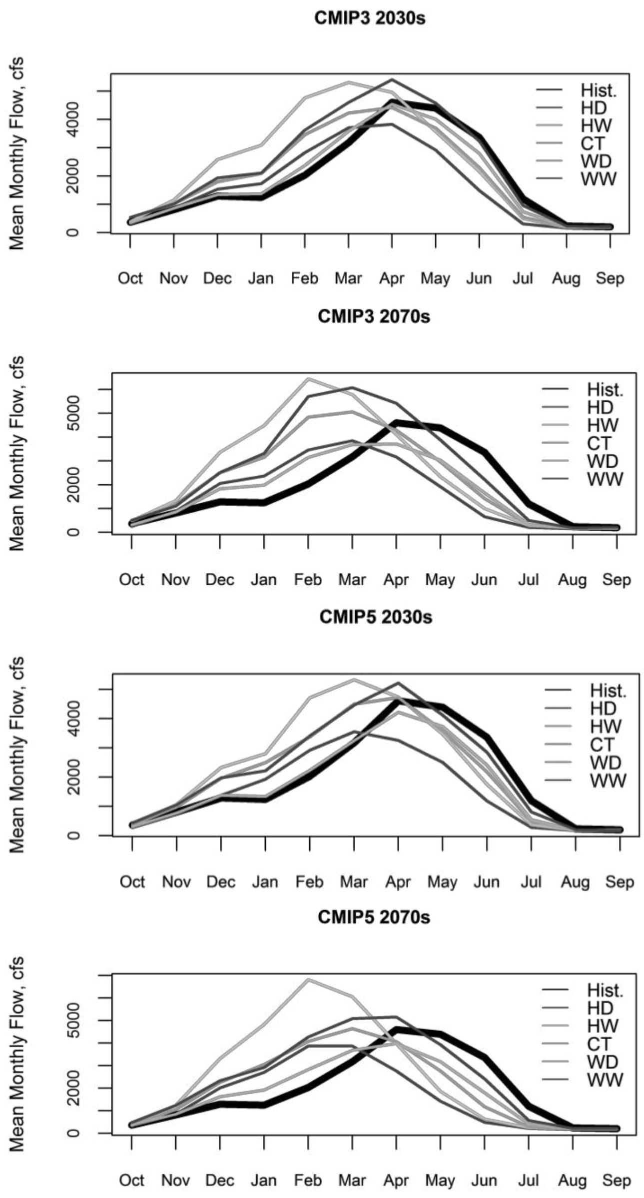


Figure 3-33. Historical and projected mean monthly hydrographs for Klamath River at Keno, OR (USGS ID 11509500)

The projected shifts in streamflow volume and timing for Keno, Oregon are typical of those sub-basins within the Klamath River Basin that are influenced in part by snowmelt. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume. Wetter scenarios indicate greater increases, while drier scenarios indicate anywhere from a slight decrease in flow volume to a slight increase in flow volume (figures not shown).

The seasonality of streamflow, in particular low flow periods, is of interest to water managers since there is often limited supply for numerous competing resources during low flow periods. At the same time, natural streamflow variability, including low flows, serves an important function for a river ecosystem. Richter et al. (1997) discuss an approach for setting streamflow-based targets for ecosystem management. The approach is based on the notion that streamflow characteristics are useful indicators for assessing ecosystem integrity over time. One of the identified indicators is the annual 7 day minimum of flow. As part of the assessment of future water supply, we evaluated projected changes in the 7Q10 low flow frequency statistic. This statistic is defined as the lowest 7 day mean flow at a location, occurring at a 10 year recurrence interval. As one example of its application, this statistic is used to define the "critical condition" for adverse impact on aquatic biota in Washington state (Chapter 173-201A of the Washington Administrative Code). As part of this assessment, the 7Q10 low flow frequency statistic is evaluated for a number of sites throughout the Klamath River Basin.

Projected changes in the 7Q10 low flow frequency statistic were evaluated as part of the Klamath River Basin water supply assessment as a way of focusing on changes in streamflow during their seasonal low periods. Low flow periods typically occur in late summer when precipitation is low, stored water supplies have largely been consumed, and anadromous fish species begin their upstream migration to spawning grounds.

Table 3-7 summarizes projected changes in 7Q10 low flow frequency for eight selected sites throughout the Klamath River Basin. Primary projected values in the table represent the central tendency, while the values in parenthesis represent the range of the five HDe climate change scenarios for CMIP3 and CMIP5 for each future time horizon. Projected changes were computed as a ratio between the projected value and the historical value. Values greater than one indicate an increase in the 7Q10 low flow, while values less than one indicate a decrease in the 7Q10 low flow (these are shown in bold in the table).

Table 3-7. Summary of ratios between projected and historical 7Q10 low flow frequency statistics for various sites within the Klamath River Basin

Site ID	Site Name	Hist. 7Q10 (cfs)	2030s CMIP3	2030s CMIP5	2070s CMIP3	2070s CMIP5
00020	Sprague R near Chiloquin	68.6	1.03 (**0.943**-1.06)	1.00 (**0.955**-1.05)	1.01 (**0.917**-1.07)	1.01 (**0.927**-1.07)
00026	Klamath R blw Iron Gate Dam	167	**0.989** (**0.965**-1.01)	**0.989** (**0.970**-1.01)	**0.994** (**0.949**-1.01)	**0.995** (**0.952**-1.01)
00004	Klamath R at Orleans	313	**0.998** (**0.980**-1.01)	**0.995** (**0.982**-1.01)	**0.996** (**0.969**-1.01)	**0.994** (**0.977**-1.01)
00029	Klamath R near Klamath	443	1.00 (**0.983**-1.00)	**0.997** (**0.989**-1.00)	**0.998** (**0.977**-1.00)	**0.996** (**0.981**-1.00)
00022	Salmon R at Somes Bar	23.4	**0.966** (**0.932**-1.01)	**0.979** (**0.957-0.966**)	**0.949** (**0.940-0.996**)	**0.983** (**0.953-0.987**)
00031	Shasta R near Yreka	29.2	1.01 (**0.990**-1.01)	1.01 (**0.979**-1.01)	1.02 (**0.990**-1.02)	1.02 (**0.979**-1.02)
00032	Scott R near Ft Jones	25.9	1.02 (1.01-1.04)	1.04 (1.01-1.05)	**0.996** (**0.996**-1.03)	1.07 (**0.981**-1.07)
00034	Trinity R at Hoopa	99.4	1.01 (1.00-1.01)	1.01 (1.00-1.02)	1.02 (1.00-1.02)	1.01 (1.01-1.02)

Note: Primary values represent the central tendency HDe scenario. Values in parenthesis represent the range of the five HDe climate change scenarios. Values above 1 indicate an increase. Values less than 1 indicate a decrease (shown in bold).

Select sites on the Sprague, Shasta, Scott, and Trinity Rivers are projected to experience increases in 7Q10 low flows for the 2030s and 2070s central tendency, compared with the historical period; however, projections range from slight decreases to slight increases. Projected increases are largely due to projected increases in precipitation. The Trinity River site (00034) is the only site evaluated where the entire range of projections indicate an increase in the 7Q10 low flow statistic. Select sites including three on the mainstem Klamath River (below Iron Gate Dam, at Orleans, and near Klamath) and one on the Salmon River are projected to experience decreases in the 7Q10 low flow central tendency, compared with the historical baseline; however, projections range from slight decreases to slight increases. The Salmon River site (00022) is the only one evaluated where the entire range (except for the 2030s CMIP3) indicates a decrease in the 7Q10 low flow statistic. Projected decreases are likely due to the combined effects of increased precipitation, increased temperature,

Future Availability – Runoff Quantity and Timing

For those basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

and increased ET. It should be noted that projections based on CMIP3 and CMIP5 show similar results in their central tendency.

Projections shown in Table 3-7 are based on streamflow generated by the VIC hydrologic model which represents natural flow, absent of management effects such as withdrawals and groundwater pumping. Combined effects of changes due to climate change and changes in management practices may alleviate or exacerbate projected changes in low flows in the Klamath River Basin. It should be stressed that the historical values presented in Table 3-7 are lower than those typically experienced in the watershed. These values are based on the lowest 7-day running mean that has a 1:10 chance of occurrence. Such an occurrence would likely occur in a prolonged drought condition where groundwater levels (which would typically provide supplemental baseflow) are also negatively impacted. In addition, it should be noted that the VIC model does not represent complex surface and groundwater interactions and therefore may not generate realistic baseflow in a heavily groundwater influenced watershed such as the Klamath River Basin. Additional discussion related to VIC model limitations is provided in Appendix B, Supplemental Information for Assessment of Water Supply.

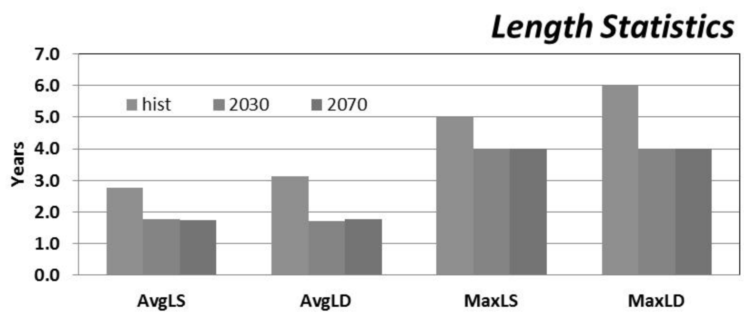
3.7.3 Changes in Drought and Surplus based on Paleo Conditioned Streamflow Projections

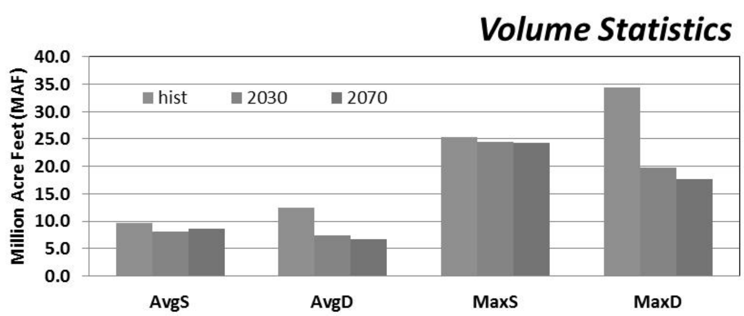
Using the approach described in Section 3.5.1.3, Deriving Paleo-Conditioned Streamflow Projections, drought and surplus statistics were analyzed for all HDe scenarios to characterize projected changes in droughts and surpluses. Drought and surplus statistics may be generated at any streamflow location in the Klamath River Basin using this approach. For the Klamath River Basin water supply assessment, we focus on results at the Klamath River near Klamath, California, which represents the integrated response to drought and surplus throughout the basin since it is close to the mouth of the river. Results are summarized graphically for the 2030s and 2070s for CMIP5-based central tendency scenarios in Figure 3-34. The data behind the figure, in addition to other HDe climate change scenarios, is summarized by Tables B-1 and B-2 in Appendix B, Supplemental Information for Assessment of Water Supply.

> **Future Availability – Droughts and Wet Periods**
>
> Analyses of surplus and drought statistics based on the paleo record are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes.

Overall, the surplus and drought statistics are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes. The projections correspond

with projections of increased precipitation overall in the Klamath River Basin for both future time horizons (2030s and 2070s). In spite of these statistics pointing to wetter conditions, the maximum surplus volumes are estimated to be nearly equal to the historical maximum surplus. The paleo-hydrologic analysis provides a way to superimpose variability by altering sequences, and for water systems the sequence in which wet and dry spells occur is critical.





Note: AvgLS and AvgLD: average length of surplus and drought, respectively. MaxLS and MaxLD: maximum length of surplus and drought, respectively. AvgS and AvgD: average surplus and drought, respectively MaxS and MaxD: maximum length of surplus and drought, respectively.

Figure 3-34. Surplus and drought statistics for the paleo-conditioned CMIP-5 central tendency climate scenario

3.7.4 Changes in Groundwater Supply

The impacts of climate change on groundwater supplies were evaluated for three primary groundwater basins within the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys. Similar to the assessment of surface water supplies, this assessment focuses on results based on CMIP5 projections. Figures similar to those presented below but based on

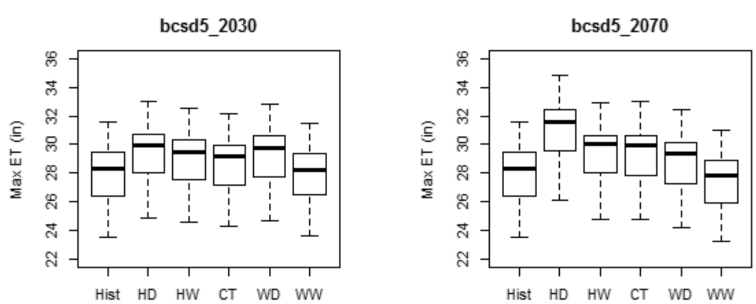
CMIP3 projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. This assessment also focuses on groundwater impacts as a result of projected changes in climate and surface water hydrology (as well as population for the Scott and Shasta Valleys) and does not consider changes in pumping or other changes in water management.

3.7.4.1 Upper Klamath Basin

The following analysis of climate change impacts focuses first on the perturbed inputs of maximum ET and mean annual recharge for the projected MODFLOW simulations, and then on MODFLOW simulation results including projected changes in groundwater elevations and discharge to surface water.

Inputs

Projections for the three perturbed MODFLOW input terms are first discussed to provide context for the discussion of projected changes in groundwater elevations and discharge. Figure 3-35 shows historical and projected mean maximum ET (as defined in the approach) for the five HDe climate change scenarios on an annual basis. As described in the approach, projected maximum ET values were computed based on annual change factors applied to historical maximum ET. The figure shows that mean annual maximum ET is projected to increase for the 2030s and 2070s, compared with the historical period, when looking at corresponding percentile levels. For the 2030s, the drier scenarios (HD and WD) appear to have slightly larger increases than the wetter scenarios. For the 2070s, the HD scenario indicates a larger increase in maximum ET than all other scenarios.



a) b)

Notes:

1. The heavy black line represents median of values across the 47 VIC cells within the Upper Klamath Basin MODFLOW model domain that contains evapotranspiration cells (defined by Gannett et al. [2012] Figure 4), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

Figure 3-35. Summary of projected mean annual maximum ET for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years

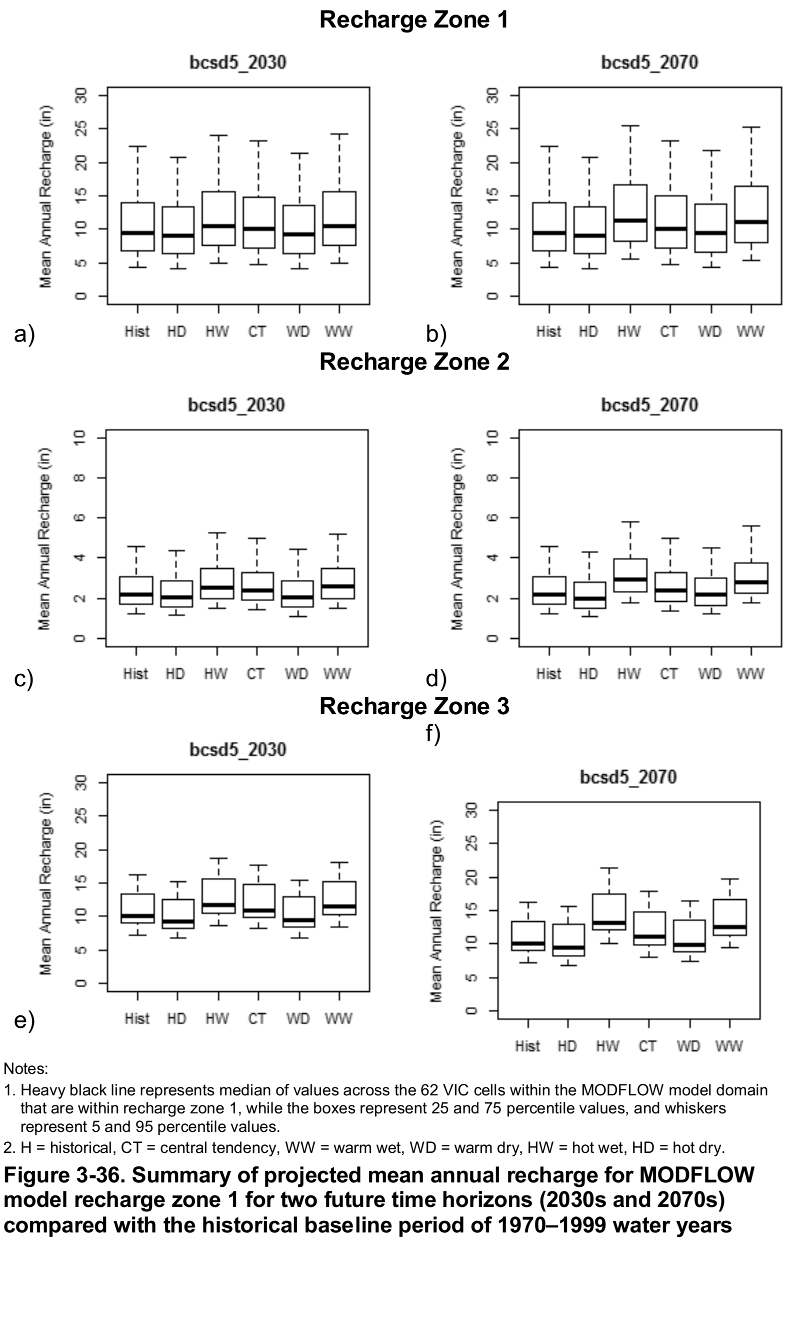
Table 3-8 summarizes the projected increases in the central tendency of mean annual maximum ET for the 2030s and 2070s, for projections based both on CMIP3 and CMIP5. Results show greater increases in maximum ET for projections based on CMIP3 than those based on CMIP5.

Table 3-8. Summary of central tendency projections of maximum ET for the 2030s and 2070s, compared with the historical baseline (1970–1999).

Central Tendency Projections	2030s	2070s
CMIP3	+4.5%	+7.1%
CMIP5	+3.3%	+5.7%

Projected recharge was input into future simulations of the Upper Klamath Basin MODFLOW model for five HDe climate change scenarios (for two future time periods and both CMIP3 and CMIP5), based on unique historical precipitation-recharge relationships by recharge zone. Figure 3-36 illustrates box plots of projected mean annual recharge by zone based on CMIP5 projections (refer to Figure 3-10 for identification of recharge zones). In general, projections of recharge are similar between future time horizons, both in magnitude and when considering the relative change across different climate change scenarios. Recharge zone 1 has a greater range of recharge (as evidenced by the difference between 5th and 95th percentile values) than zones 2 or 3. Also, recharge zone 2 has substantially lower recharge than the other zones, including the historical values. Lower recharge in zone 2 likely corresponds with less precipitation and snowpack to help drive recharge. Projected changes in mean annual recharge for zone 1 range from increases to small decreases. Wetter scenarios generally indicate increases in recharge, while drier scenarios generally indicate decreases, particularly looking at the median (50^{th} percentile) change.

Table 3-8 summarizes mean annual recharge by zone, and basin-wide, for the central tendency (2030s and 2070s, CMIP3 and CMIP5). For the 2030s, projected changes in recharge differ substantially between CMIP3- and CMIP5-based scenarios. However, by the 2070s CMIP3- and CMIP5-based scenarios are more similar. In fact, the difference in projected recharge change for zone 1 is almost as great between CMIP3 and CMIP5 for the 2030s as the difference between the 2030s and 2070s based on CMIP3. These results were verified; however, it illustrates how closely recharge projections correspond with projections of future precipitation. Basin-wide precipitation changes for the central tendency are projected to be about +2.4 percent (based on CMIP3) and +4.1 percent (based on CMIP5) for the 2030s and about +5.2 percent (based on CMIP3) and +6.1 percent (based on CMIP5) for the 2070s. Projections of recharge for other HDe climate change scenarios show similar correspondence with precipitation projections.



Notes:

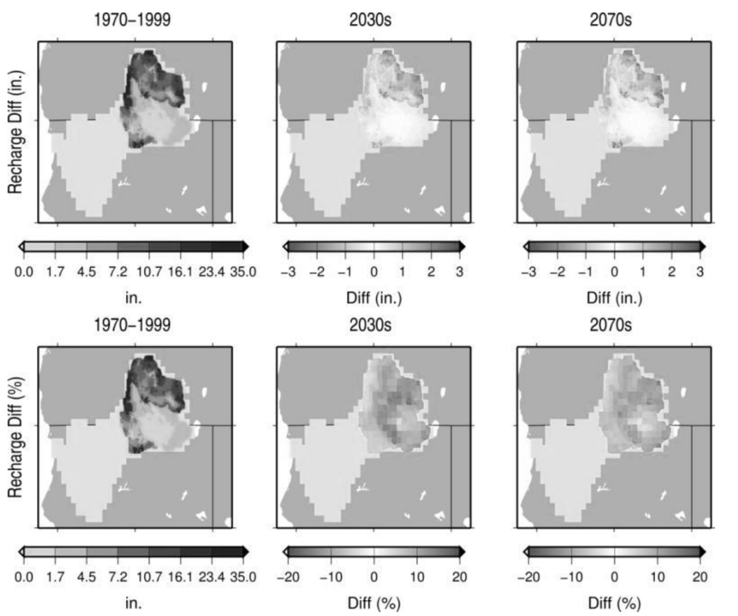
1. Heavy black line represents median of values across the 62 VIC cells within the MODFLOW model domain that are within recharge zone 1, while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

Figure 3-36. Summary of projected mean annual recharge for MODFLOW model recharge zone 1 for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years

Table 3-9. Summary of central tendency projected change in mean annual recharge by zone for the 2030s and 2070s, compared with the historical baseline (1970–1999 water years)

Central Tendency Projections	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Recharge Zone 1	+3.0%	+6.1%	+7.9%	+6.5%
Recharge Zone 2	+4.3%	+8.9%	+8.0%	+9.4%
Recharge Zone 3	+4.6%	+8.8%	+10.5%	+10.0%
Basin Wide	+3.4%	+8.4%	+8.8%	+8.2%

Figure 3-37 spatially illustrates historical and projected change in mean recharge for CMIP5-based central tendency scenarios (2030s and 2070s) based on data used as input by the MODFLOW model for the Upper Klamath Basin. The left column contains identical panels (top row and bottom row) showing the historical seasonal mean recharge (in inches) used in the calibrated model (similar to Figure 3-10). The middle and right columns contain projected change for the 2030s and 2070s, respectively (top row in inches, bottom row in percent change).



Note: The left-hand column illustrates the historical values (top row and bottom row are identical), while the middle and right-hand columns illustrate change (top row in inches, bottom row in percent change) from 1970-1999 values to the 2030s and 2070s, respectively.

Figure 3-37. Comparison of change in mean annual recharge to groundwater for the central tendency climate scenarios, using groupings of GCMs from CMIP5

Outputs

The Upper Klamath Basin MODFLOW model was implemented using projected inputs as previously described. For the purpose of the Klamath River Basin water supply assessment, historical pumping was used to explore the effects of climate change alone on the groundwater balance.

The MODFLOW model computes an overall groundwater budget on a seasonal timestep. Table 3-10 summarizes projected mean changes in the primary output components of the budget for the central tendency HDe scenario. These components consist of groundwater discharge to drains, evapotranspiration, and groundwater discharge to streams. Drains include surface water conveyances such as constructed canals and ditches and natural springs. Units for discharge to drains may be described as cubic feet per second (cfs) per grid cell, where discharge (in cfs) is the mean computed over the simulation period (water years 1970–1999) and across all MODFLOW grid cells designated as drains. Basin-wide changes in groundwater discharge to drains are projected to increase by less than two percent for both the 2030s and 2070s. Considering four central tendency scenarios (CMIP3 2030s and 2070s as well as CMIP5 2030s and 2070s), the greatest increase in discharge to drains is projected for the CMIP5-based 2030s scenario. The integration of projected changes in temperature and precipitation in the modeled domain (i.e., the Upper Klamath Basin) indicate greater increases for the 2030s than for the 2070s based on CMIP5.

Units for ET are inches, where ET is the mean computed over the simulation period and across all MODFLOW grid cells designated as having ET. Projected changes in mean ET indicate increases according to all central tendency projections (Table 3-10), with greater increases projected for the 2070s than for the 2030s. ET corresponds more closely with temperature than with precipitation. Projections of annual temperature (Table 3-5) indicate similar projected increases in the central tendency for the 2030s (CMIP3 and CMIP5) and similar yet greater increases for the 2070s.

Discharge to streams is presented in units similar to discharge to drains, namely mean discharge (cfs) per MODFLOW grid cell designated as stream. Seasonal mean discharge to streams is projected to increase, with the greatest increases projected for the CMIP5 2030s and the CMIP3 2070s scenarios (Table 3-10).

Table 3-10. Average percent change in mean groundwater balance variables

Central Tendency Projections	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
GW Losses to Drains	+0.4%	+1.8%	+1.2%	+1.3%
GW Losses to ET	+4.1%	+5.2%	+7.3%	+6.4%
GW Losses to Streams	+2.0%	+5.2%	+5.3%	+4.8%

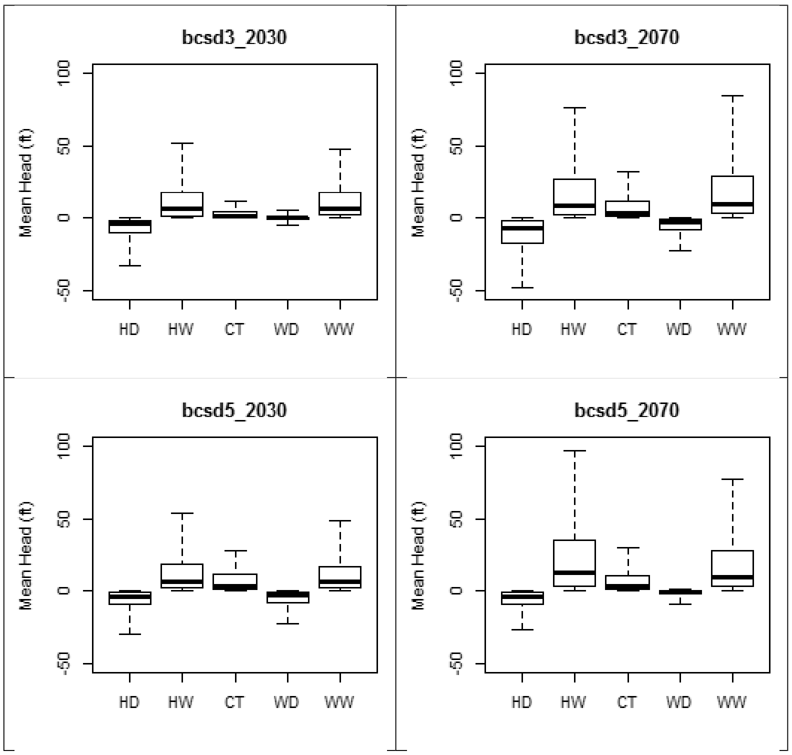
In addition to projected changes in the overall groundwater budget, projected changes in groundwater head for the three vertical layers represented in the MODFLOW model were evaluated as part of the water supply assessment. Groundwater head corresponds with the elevation of the water table. Projected changes in mean groundwater head for the central tendency scenario (2030s CMIP3 and CMIP5 as well as 2070s CMIP3 and CMIP5) are summarized in Table 3-11. Groundwater head is projected to increase by between 1.8 and 7.8 feet for the 2030s (central tendency) and between 4.4 and 8.2 feet for the 2070s.

Table 3-11. Average change in groundwater head due to MODFLOW simulations based on projected changes in all variables for the central tendency projection

Central Tendency Projected Change (in feet)	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Change in Head, All, Layer 1	3.1	7.8	8.2	7.7
Change in Head, All, Layer 2	2.0	5.0	4.9	4.8
Change in Head, All, Layer 3	1.8	4.6	4.4	4.3

Note: “All” variables include recharge and max ET

Figure 3-38 focuses on layer 1 and shows how projected changes in groundwater head (in feet) for the central tendency compare with other HDe scenarios. Layer 1 is presented because it has the greatest sensitivity to projected climate changes. The wetter scenarios (HW and WW) generally indicate larger increases in groundwater head than the central tendency, while the drier scenarios (HD and WD) indicate smaller increases or even decreases in groundwater head, depending on the type of projection (CMIP3 or CMIP5) and time horizon (2030s or 2070s).

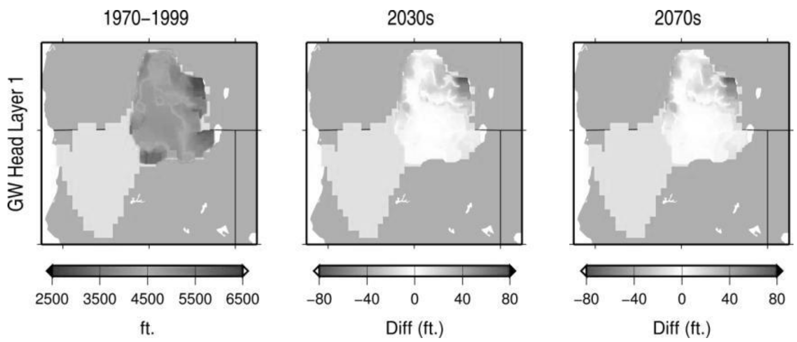


Notes:

1. The heavy black line represents median of values across the roughly 32,000 cells within the MODFLOW model domain (MODFLOW spatial resolution), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW=– hot wet, HD = hot dry.

Figure 3-38. Summary of difference in projected mean groundwater head for MODFLOW model layer 1 for 2030s and 2070s time horizons compared with the historical baseline period of 1970–1999 water years

Projected changes in groundwater head for layer 1 for the CMIP5-based central tendency scenario are presented spatially in Figure 3-39. The left column illustrates historical mean seasonal groundwater head over the simulation period 1970–1999 (water years), while the middle and right columns illustrate projected changes in feet for the 2030s and 2070s, respectively. The figure shows that projected changes may result in a substantial depth of water, up to about 50 feet in the northeast portion of the basin. As a point of reference, land surface elevations in the Upper Klamath Basin modeled domain range from 2,500 feet to 8,500 feet.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate change (in feet) from 1970–1999 values to the 2030s and 2070s, respectively.

Figure 3-39. Comparison of change in mean groundwater head in the uppermost layer of the MODFLOW model for the central tendency climate scenario, using groupings of GCMs from CMIP5

The following analysis summarizes projected discharge to individual stream reaches across the Upper Klamath Basin, as defined in Figure 3-40. Projections summarized in Table 3-12 indicate increases in groundwater discharge for all designated stream reaches. Similar to projections of precipitation and recharge, CMIP5 projections for the 2030s show larger increases than CMIP3 projections, while for the 2070s CMIP3 projections show larger increases than CMIP5. Also, CMIP3 2030s projections show the greatest change overall (even greater than for the 2070s). As previously discussed, the relative differences between scenarios are a result of the process of grouping GCM projections as part of the HDe approach. The smallest projected increases are for Lost River and Wood River reaches, while the largest projected increases are for Sycan and Sprague River reaches.

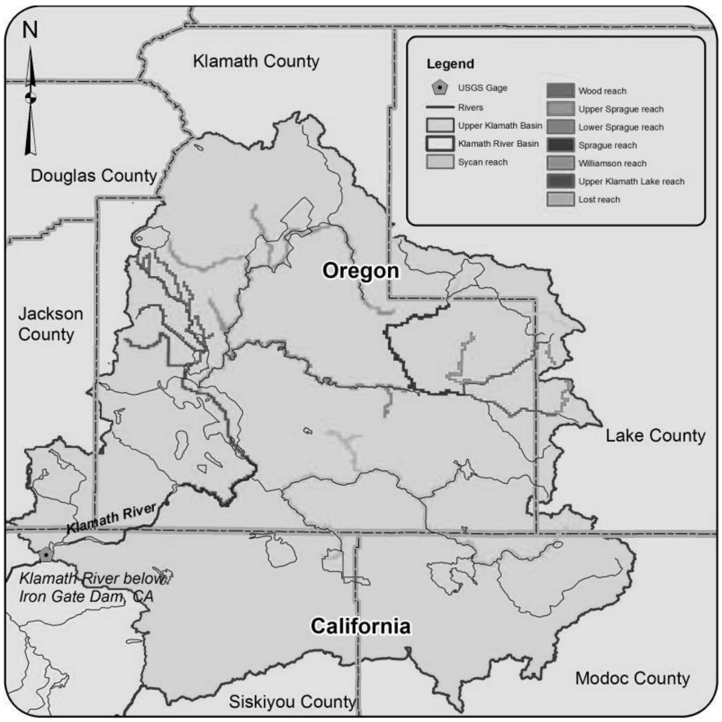


Figure 3-40. Overview map of MODFLOW stream reaches analyzed as part of the Klamath River Basin Study water supply assessment

Table 3-12. Average percent change in groundwater losses to streams over the simulation period for central tendency projections

Central Tendency Projections (Percent Change)	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Lost River	+0.7%	+2.6%	+1.9%	+1.7%
Lower Sprague	+2.8%	+6.5%	+6.8%	+5.3%
Sprague	+3.5%	+9.1%	+8.7%	+8.0%
Sycan	+5.2%	+13%	+13%	+12%
Upper Klamath Lake	+1.2%	+3.5%	+4.0%	+3.6%
Upper Sprague	+2.6%	+7.4%	+6.8%	+6.7%
Williamson	+2.7%	+6.9%	+7.6%	+6.2%
Wood River	+1.0%	+3.0%	+3.6%	+3.1%

3.7.4.2 Scott Valley

The groundwater screening tools developed for the Scott and Shasta Valleys allow for the evaluation of projected changes in mean groundwater elevation. Figure 3-41 illustrates projected changes in monthly groundwater elevations for the two future time periods based on CMIP5 (panels a and b). Individual boxes in each panel represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. The historical simulation period is calendar years 1980–1999, while the future simulation period is effectively a 50-year period that represents the characteristics of the chosen future time horizon (2030s or 2070s, in this case). Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period in the absence of any changes in groundwater use beyond that associated with population growth. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases.

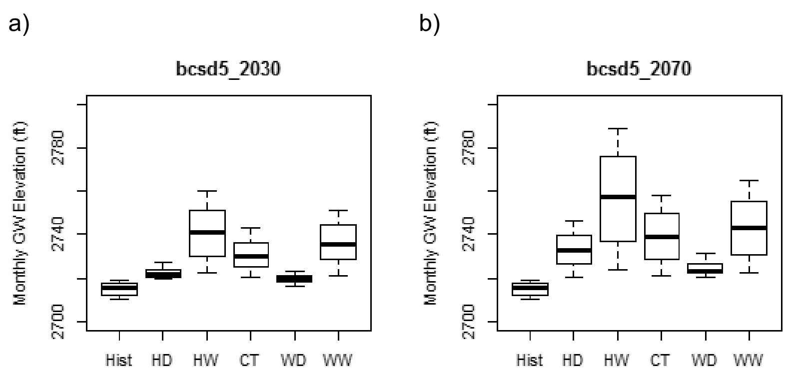


Figure 3-41. Summary of projected groundwater elevation for Scott Valley

The central tendency projections fall in between, with a median projection of a 15 foot increase in groundwater elevation by the 2030s and a 23 foot increase by the 2070s. To provide some context, the Scott and Shasta Valleys experienced fluctuations in annual groundwater elevation of about 20 feet over the period 1980–1999. Projected increases in groundwater elevation in the Scott Valley correspond with projected increases in precipitation in the watershed. Projected increases in actual ET computed by the VIC surface water hydrologic model (based on an assumption of natural vegetation) are not great enough to offset the projected increases in precipitation, resulting in greater potential for groundwater recharge.

It is notable that the HW scenario based on CMIP5 indicates a greater increase in groundwater elevation than the cooler (WW) scenario. One would expect the HW scenario to have a smaller increase in groundwater elevation due to greater ET losses. However, the HW scenario may actually be wetter than the WW scenario, which may compensate for any additional ET losses due to higher temperatures.

CMIP3- and CMIP5-based projections are similar for the two future time horizons; however CMIP5-based projections generally result in greater increases in groundwater elevation, corresponding with greater increases in precipitation compared with CMIP3. Individual scenarios may also differ to due to the automated selection process for individual GCM projections within a quadrant (refer to Section 3.5.1.1, Climate Projections for additional explanation of the projection selection procedure).

3.7.4.3 Shasta Valley

Projected changes in monthly groundwater elevation for the Shasta Valley are summarized in Figure 3-42 (panels a and b) for the two future time periods based on CMIP5. Box plots are similar to those in Figures 3-41 and represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations in the Shasta Valley.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. The central tendency scenarios based on CMIP5 indicate about a 24-foot increase in groundwater elevation for the 2030s and a 25-foot increase for the 2070s, compared with the historical baseline. To provide context, historical Shasta Valley groundwater elevations fluctuated approximately 20 feet over the historical simulation period. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases. The WW scenario indicates the greatest projected change, likely because ET rates are probably lower than in the hotter scenarios and more water may be available for groundwater recharge.

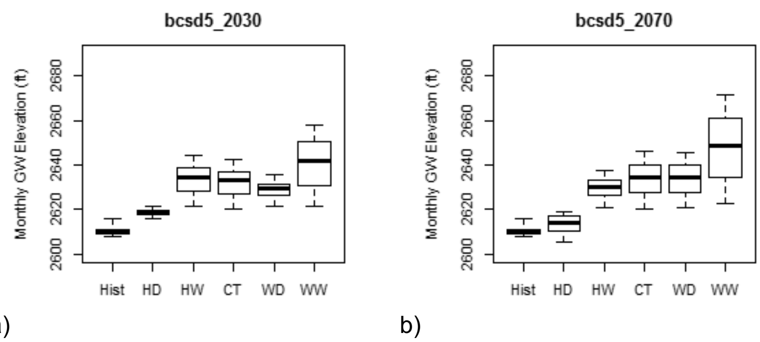


Figure 3-42. Summary of projected groundwater elevation for Shasta Valley

A majority of the projections for the 2070s show greater increases in groundwater elevation than for the 2030s, with the exception of the hotter scenarios (for example, CMIP3-based HD and CMIP5-based HD and HW). A smaller increase in groundwater elevation in the 2070s compared with the 2030s, despite greater projected increases in precipitation, may be due to the combined effects of increased ET corresponding with higher temperatures.

When comparing CMIP3-based projections with CMIP5-based projections, the differences in median projections of monthly groundwater elevation are more dissimilar than would be expected. For example, the median monthly change in groundwater for the 2070s compared with the historical baseline is almost 5 feet for CMIP5 and 12 feet (more than double) for CMIP3. This example illustrates the importance of considering a wide range of climate scenarios (including both CMIP3 and CMIP5) in the analysis of water supply impacts.

Future Availability – Scott and Shasta Valley Groundwater

Projected monthly groundwater elevations in the Scott and Shasta Valley alluvial aquifers (as defined by CDWR Bulletin 118) for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. However, the projected changes are within or close to the historical fluctuations in groundwater elevation in the two basins (on the order of 20 feet for both basins).

3.8 External Factors Affecting Water Supply

In addition to detailed analysis of historical and projected surface and groundwater supplies, this chapter also discusses existing knowledge and research regarding historical and projected sea level rise and wildfire risk. We acknowledge that these phenomena have and may continue to change due to projected changes in climate, and they are important considerations when analyzing water supplies in the Klamath River Basin. Sea level rise poses many risks to the coastal landscape and population. Projected increase in wildfires also poses risks to water supply through increased sediment loads to lakes, reservoirs, and streams, potential damage to water supply infrastructure, and changes to landscape characteristics that affect water temperatures, infiltration dynamics, and runoff timing, among other things.

3.8.1 Projected Sea Level Rise

A warming climate causes global sea level to rise by two primary mechanisms: increasing ocean volume due to expanding sea water associated with warming, and the melting of land ice. Other, more regional phenomena impact the extent of sea level rise off the coast of Oregon and California. For instance, climate patterns such as El Niño and the PDO affect winds and ocean circulation, raising local sea level during warm phases (e.g., El Niño) and lowering sea level during cool phases (e.g., La Niña). Large El Niño events can raise coastal sea levels by 4 to 12 inches for several winter months (NRC, 2012). Tectonics may also affect regional sea levels. In some regions, tectonics may cause the land surface to rise in some regions and fall in others, indicating rising and falling sea levels, respectively. For example, records from 12 west coast tide gages indicate local variability in sea-level change along the coast, although most of the gages north of Cape Mendocino, California, show that relative sea level has been falling over the past 6–10 decades (NRC, 2012). Sea level projections due to climate change are confounded by changes due to naturally occurring phenomena described above.

This section summarizes the findings from three primary documents describing the impacts of climate change on sea level rise in the coastal region of the Klamath River Basin. The first is a 2012 assessment by the National Research Council of best available science with respect to sea level rise in California, Oregon, and Washington. The second document is the Public Draft Report of the most recent National Climate Assessment, which was published in 2013. At the completion of the Klamath River Basin Study water supply assessment, the final National Climate Assessment Report was yet not complete. The third document is the State of California Sea Level Rise Guidance Document, which was published in 2013 by the Coastal and Ocean Working Group of the California Climate Action Team. This document provides guidance for incorporating sea-level rise projections in planning and decision-making for projects in California, but also summarizes existing knowledge on projected sea level rise.

National Research Council (2012) summarized past and projected sea-level rise for the coasts of California, Oregon, and Washington. The assessment states that

vertical land motion from geological processes and human activities, estimated by global positioning system (GPS) measurements, show that much of the western coast north of Cape Mendocino (including the coastal region of the Klamath River Basin) is rising about 0.06–0.1 inches per year (NRC, 2012). Flooding and erosion in coastal areas is already occurring and is damaging some areas of the California coast during storms and extreme high tides (Garfin et al., 2014). Rising land masses may exacerbate the issue of coastal flooding and erosion.

Projections for the Washington, Oregon, and California coasts north of Cape Mendocino indicate that sea level is projected to change between -2 inches (sea-level fall) and +9 inches by 2030, between -1 inch and +19 inches by 2050, and 4–56 inches by 2100 (NRC, 2012). Sea level is likely to rise at a greater rate during the 21st century than it has in the 20th century. Figure 3-43 illustrates projected sea level rise (in centimeters) along the entire west coast of the U. S.

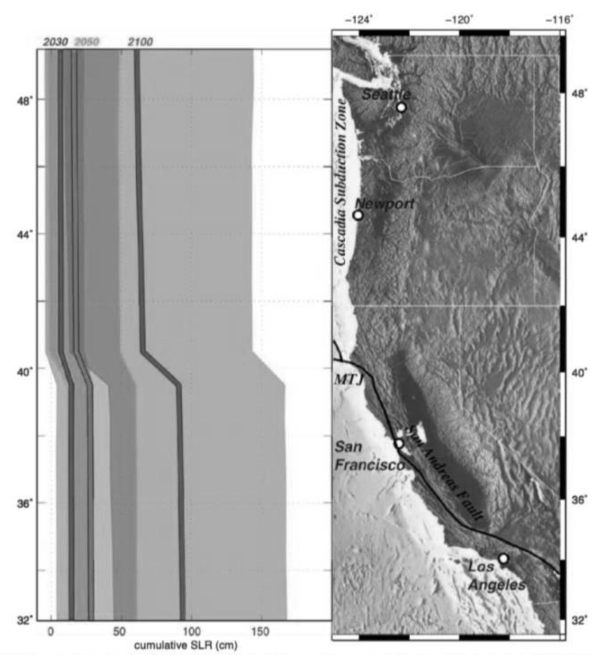


FIGURE S.1 Projected sea-level rise off California, Oregon, and Washington for 2030 (blue), 2050 (green), and 2100 (pink), relative to 2000, as a function of latitude. Solid lines are the projections, and shaded areas are the ranges. Ranges overlap, as indicated by the brown shading (low end of 2100 range and high end of 2050 range) and blue-green shading (low end of 2050 range and high end of 2030 range). MTJ = Mendocino Triple Junction, where the San Andreas Fault meets the Cascadia Subduction Zone.

Source: NRC, 2012, Figure S.1

Figure 3-43. Projected sea level rise along the west coast of the United States

Risks associated with projected sea level rise include the increased risk of coastal flooding, storm surge inundation, coastal erosion and shoreline retreat, and wetland loss. NRC (2012) highlights the significant risk posed to the region north of Cape Mendocino from a large earthquake (magnitude greater than 8) along the Cascadia Subduction Zone, which could cause significant land subsidence resulting in instantaneous sea-level rise as well as a tsunami. In addition, many coastal wetlands, tidal flats, and beaches will likely decline in quality and extent as a result of sea level rise.

3.8.2 Projected Wildfire Risk

The sections of the Public Draft of the most recent National Climate Assessment most relevant to the area of this study (Garfin et al., 2013 for the southwest U.S.; Mote et al., 2014 for the northwest U.S.) summarize past and projected trends in wildfire risk along the west coast, including the greater region surrounding the Klamath River Basin. Increased warming, due to climate change, and drought have increased wildfires and impacts to people and ecosystems in the Southwest, including California. A number of studies have documented increases in wildfire fire season duration and fire frequency and project increases in the probability of large wildfires. Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s (Mote et al., 2013). Between 1970 and 2003, warmer and drier conditions increased the burned area in western U.S. mid-elevation conifer forests by 650 percent (Westerling et al., 2006). Models project up to 74 percent more fires in California in the future (Westerling et al., 2012).

Some of the causes of increased wildfire risk include projected decreases in late summer stream flows in some parts of the Klamath River Basin, changes in the timing and amount of recharge, increases in evapotranspiration, and declines in the groundwater table due in part to increases in pumping demand. Potential increases in water deficits may increase tree stress and mortality, tree vulnerability to insects, and fuel flammability (Mote et al., 2013). Also, an increased risk of watershed vegetation disturbance is anticipated due to increased wildfire potential (Interior and CDFG, 2011).

3.9 Uncertainties Associated with Impacts Assessment Approach

In accordance with common practice, the impacts assessment methodology employed here is based on using a series of models with the outputs of one model serving as the input to the next model. Since there are uncertainties associated with each model step, and the inputs driving each model step are themselves uncertain, this can lead to a “cascade of uncertainty” (IPCC 2007, here), although there may be situations where one model’s tendency to over- or under-estimate may be countered at least to some extent by another’s tendency to err in the other direction. While this study has not developed an estimate of the cumulative

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uncertainties in the results based on this methodology, this section summarizes uncertainties associated with various aspects of the Klamath River Basin Study water supply assessment, including the use of climate change scenarios as well as surface and groundwater hydrologic models to evaluate climate change impacts. Additional discussion regarding the use of GCM climate projections and applied downscaling techniques is provided by Reclamation (2011d). The nature of these uncertainties is only briefly described below.

3.9.1 Global Climate Projections, Modeling, and Downscaling

The climate projections considered in this report represent a range of future greenhouse emission pathways (Reclamation, 2011d); however, uncertainties associated with estimating these pathways, including those introduced by assumptions of global growth and land use, are not explored in this analysis. Additional uncertainty is associated with feedbacks such as the influence of human-produced aerosols in the atmosphere.

GCMs themselves have associated uncertainty with respect to their initial conditions, inputs, representation of physical processes, and assumptions regarding the sensitivity of climate variables to changes in greenhouse gas concentrations and other parameters. Issues with GCMs are compounded by the fact that it is currently difficult, if not impossible, to validate GCM results using datasets that were not used to develop and tune these GCMs. Different simulations using the same model may have quite different realizations of longer timescale climate patterns. Regarding representation of physical processes, the most recent generation of GCM simulations (based on CMIP5) incorporate, in many cases, improved understanding of the climate system. By using both CMIP3- and CMIP5-based projections as part of the Klamath River Basin Study water supply assessment, we may evaluate the differences in results based on a wider range of model constructs. GCMs may have biases toward being too wet, too dry, too warm, or too cool, and these should be identified and accounted for in climate change impacts studies (Reclamation, 2011d). Although there is very high confidence that the CMIP5 models show long-term trends consistent with historical observations, there is substantial (several-fold) disagreement between models and observations over the rate of warming for 1998-2012. For example, Bindoff et al. (2013) acknowledge that the observed global mean surface temperature has shown a much smaller increasing linear trend over 1998-2012 than the suite of CMIP5 models, despite the fact that half of this period was included in the data that was used to develop/tune the models. Due to internal climate variability, in any given 15-year period the observed trend in the global mean surface temperature sometimes can lie near one end of a model ensemble.

The uncertainty due to the mismatch between simulated mean global surface temperature and observations is exacerbated by the fact that the reliability of model results declines and uncertainty expands as one goes from the global scale to finer (i.e., regional and local) scales as is necessary to do an analysis for the Klamath River Basin. This is particularly true for precipitation.

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(2) US Climate Change Science Program. Climate Models: An Assessment of Strengths and Limitations. Washington, DC: U.S. Climate Change Science Program and the Subcommittee on Global Change Research; 2008.

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Generally, to reduce inconsistencies between simulated climate and observed conditions, projections are bias corrected. The term bias correction refers to the use of a statistical procedure to adjust global climate model projections to remove differences between simulated and observed climate conditions computed over a common historical time period. This method, however, assumes that biases are systematic and their distributions over the historical time period would be similar to a future time period. Primary causes of bias in global climate model simulations include bias resulting from the coarse resolution of global climate models and the corresponding inability to resolve important stationary features such as land surface topography and land-water interfaces along coastlines and the use of simplified parameterizations to represent physical processes that occur at too small a scale or are too complex to be represented physically. They could also result from biases in emission inputs, coupled biogeochemical models and estimates of climate sensitivity. Model biases can significantly affect impact studies that use climate projections to evaluate hydrologic and ecosystem response to potential changes in climate. As a result, it is prudent to apply bias correction before using global climate model outputs as inputs to other types of models, recognizing that other uncertainties persist.

Uncertainties are also associated with the methodology used to downscale information at the scale of GCMs to the regional, or watershed, scale. The Klamath River Basin Study utilizes statistically downscaled climate projections to derive HDe climate scenarios. Although these types of scenarios have been used to support numerous water resources impacts studies, uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies, such as statistical downscaling, require historical reference information use on spatial climatic patterns at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which presumably would change somewhat with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption that the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have statistical stationarity. In actuality, it is possible that such stationarity will not hold at various space and time scales, over various locations, and for various climate variables. However, the significance of potential non-stationarity in empirical downscaling methods and the need to utilize alternative downscaling methodologies remains to be established.

3.9.2 Watershed Vegetation Changes under Climate Change

In Reclamation (2011d) and related literature sources cited, the chosen approach for assessing hydrologic effects under projected climate changes is to use a surface water hydrologic model that computes hydrologic conditions, given

changes in weather, while holding other watershed features constant. The composition of vegetation might change as climate changes, and that, in turn, would affect runoff through changes to evapotranspiration and infiltration processes.

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3.9.3 Direct Effects of Carbon Dioxide on Water Use in Vegetation

Increases in CO2 concentrations also affect vegetation growth, and water use and demand in a variety of other ways. Higher CO2 levels increase biomass production via an increase in the photosynthetic rate, unless there are nutrient limitations. They also increase the intrinsic water use efficiency (WUE) of plants, that is, they transpire (or discharge) less water to the atmosphere per unit biomass product. The latter then would decrease demand for irrigation water, and increase runoff, soil moisture and groundwater recharge, unless the transpiration effect is swamped by a countervailing increase in biomass production (AR5, WG2, Chapter 4, 276; IPCC 2014, 161). In managed systems, but not in unmanaged systems, the amount of biomass production can be controlled, and nutrient limitations on photosynthesis can be surmounted, if desired.

The IPCC notes that a meta-analysis of studies at 47 sites across five ecosystem types suggests that intrinsic WUE for mature trees increased by 20.5% between the 1970s and 2000s. It also notes that other studies have detected an increase in intrinsic WUE at several forest sites and a temperate semi-natural grassland since 1857 but the increase stopped in one boreal tree species after 1970 (AR5, WG2, Chapter 4, 294). In addition, a study of 21 forest sites in the Northern Hemisphere, including 7 unmanaged forests in the midwestern and northeastern U.S., found that carbon uptake and WUE had increased at the majority of sites for the periods examined (7-18 years) (Keenan et al. 2013). That study also found that observed increase in forest water-use efficiency was larger than predicted by existing theory and 13 terrestrial biosphere models.

Based on experimental results and modeling studies, the IPCC states that it has “medium confidence that increases in CO2 up to about 600 ppm will continue to enhance photosynthesis and plant water use efficiency (WUE), but at a diminishing rate” (AR5, WG2, Chapter 4, 287), and it classifies these effects as “first-order” influences on ecosystem and hydrological responses to anthropogenic climate change (AR5, WG2, Chapter 4, 288).

However, the IPCC notes that since “… water, carbon, and vegetation dynamics evolve synchronously and interactively under climate change, it remains a challenge to disentangle the individual effects of climate, CO2, and land cover change on the water cycle.” (IPCC 2014, 160). Because of the complexities involved in modeling these effects, the Klamath River Basin Study did not factor changes in water demand, runoff, soil moisture and groundwater recharge due to the direct effects of CO2. Consequently, this is a substantial source of uncertainty that should be considered by users of this study.

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Sources:

1. AR5, WG2, Chapter 4.

2. IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summaries, Frequently Asked Questions, and Cross-Chapter Boxes. A Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. World Meteorological Organization, Geneva, Switzerland, 190 pp. 160 (See p. 160 for recharge).

3. Keenan TF, Hollinger DY, Bohrer G, Dragoni D, Munger JW, Schmid HP, Richardson AD. Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. Nature. 2013 Jul 18;499(7458):324-7.

3.9.4 Quality of Hydrologic Model Used to Assess Hydrologic Effects

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In Reclamation (2011d) and most of the cited literature sources, the chosen approach for assessing surface water hydrologic effects has typically involved using surface water hydrologic models, which may not represent key hydrologic processes related to groundwater and/or large water bodies. Reclamation (2011d) discusses these limitations, and they are illustrated in Section 3.3.2, Historical Surface Water Availability – Approach, which shows how the VIC model imperfectly reproduces historical runoff conditions. Some of these imperfections could be reduced through refined redevelopment, or calibration, of the model. Another approach for exploring the uncertainty associated with the VIC hydrologic model, which was not taken in this study, would be to apply additional surface water hydrology models and compare results across simulations.

In the case the Klamath River Basin, refinement of VIC model calibration is challenging due to the lack of available naturalized flow datasets. Reclamation (2005) showed the difficulty in developing naturalized flows in such a complex watershed. Additional efforts may be invested in this area; however, focusing on a change of projected future conditions relative to historical conditions is a scientifically defensible approach taken in numerous climate change impacts studies, and is the approach taken for the Klamath River Basin Study water supply assessment.

3.9.5 Quality of Groundwater Models Used to Assess Groundwater Effects

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Groundwater modeling in general is extremely challenging due to the complexity of most groundwater systems (the Klamath River Basin included) coupled with a general lack of sufficient data to characterize groundwater basins in great detail. The USGS has made great efforts in collecting data and developing a fine scale finite-difference MODFLOW model for the Upper Klamath Basin (Gannett et al., 2012). Despite the high level of effort taken in this study, significant uncertainties still remain about the adequacy of the model to characterize detailed groundwater dynamics in the basin. Gannett et al. (2012) discuss possible reasons for differences between observed and simulated groundwater elevations in parts of the basin, including lack of accurate information on rates and locations of pumping, and coarse vertical discretization of the model relative to the gradients of groundwater flow. Nonetheless, we may assume that historical biases in the MODFLOW model may carry through to the future. As such, we may evaluate the relative change of projected groundwater elevations and discharge compared with the historical simulation.

The Scott and Shasta Valleys have greater issues of data availability for characterizing the groundwater systems than the Upper Klamath Basin, where more resources have been invested in monitoring and evaluating the groundwater system. Monitoring wells are few and the monitoring data available for those wells is sparse, generally consisting of two or so measurements per year. In addition, CDWR Bulletin 118 was used to define groundwater basins in these regions, and these likely do not represent the complexity of groundwater aquifers that exist there. Development of groundwater models for these basins using this information poses a challenge. Furthermore, the size of these groundwater basins is much smaller than the Upper Klamath Basin, making the coarse spatial resolution of groundwater model inputs (such as precipitation, temperature, and gridded runoff) less relevant at the scale of these sub-basins. Due to these high levels of uncertainty, a statistical modeling approach was taken to simulate groundwater elevations in the Scott and Shasta Valleys. A simpler approach may be justified when uncertainty associated with input data is high. Still, the statistical models may be used to evaluate the relative change of projected groundwater elevations compared with estimated historical conditions.

3.9.6 Differences between Climate Projections from CMIP3 and CMIP5

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The above discussions of uncertainty related to climate forcings and downscaling techniques are based on analysis of projections from CMIP3. The models and scenarios of emissions used in CMIP5 differ in several ways from those used in CMIP3. First, model resolution has generally increased by a factor of 2 (i.e., CMIP5 models have, on average, twice the number of grid cells representing the atmosphere than CMIP3 models). Second, although many of the models used in CMIP5 are similar in structure to those used in CMIP3, many incorporate updated physics and added, or improved, individual process representation. Some of the models used in CMIP5 reflect a fundamental advancement in model structure by

incorporating biogeochemical cycling; this new class of models is referred to as Earth System Models. Third, there are notable differences in precipitation for some regions (e.g., greater warming over the Upper Columbia Basin, less precipitation over the northern Great Plains, and more precipitation over California and the Upper Colorado Basin). Projections showing wetter portions of California and the Upper Colorado are notable because they challenge the prevailing perspective of climate change impacts to the region that has been held since 2007 (informed by CMIP3 projections): namely, that these regions will become drier, resulting in reduced runoff. It is important to recognize that while CMIP5 offers new information, more work is required to better understand CMIP5 and its differences compared to CMIP3. In some regions, model resolution is likely the leading factor in these differences. In the North American Monsoon region, for example, the higher resolution of CMIP5 models allows these models to better capture the landward moisture transport and overland convection that results in monsoon precipitation events. These processes were not resolved in the lower resolution CMIP3 models.

The CMIP5 projections represent a new opportunity to improve our understanding of climate science, which is evolving at a rapid pace. While CMIP5 projections may inform future analyses, many completed and ongoing studies are informed by CMIP3 projections that were selected as the best information available at the time of the study. Even though CMIP5 provides the latest available suite of climate projections, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP3 projections. Current state of practice relies on one or both suites of climate projections for use in impacts studies.

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Chapter 4
Klamath River Basin Study
Assessment of Current and Future Water Demands

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Chapter 4 Assessment of Current and Future Water Demands

4.1 Introduction

Changes in water demands in the Klamath River Basin over the next 50 years are uncertain, and will depend on a number of socioeconomic and other factors. The Klamath River Basin Study aims to assess the impacts of climate change on water supply and demand in the watershed from its headwaters to the mouth, and to identify current and projected water supply shortages. This chapter of the Klamath River Basin Study report quantifies current water demand and projected future water demand in a changing climate. Future demand projections are meant to be sufficiently broad to capture the plausible ranges of uncertainty. Projected water demands are evaluated along with the projected supply conditions in Chapter 3 as part of a system reliability analysis to identify potential water supply shortages in the Klamath River Basin, which is presented in Chapter 5. The system reliability analysis, presented in Chapter 6, identifies any potential shortfalls between demand and supply, as well as potential strategies to plan for and reduce gaps.

Statistically downscaled climate projections from general circulation models (GCMs) inform both the demand and supply analyses. As discussed in Chapter 3, two sets of downscaled GCM output were used in the analyses: Coupled Model Intercomparison Project Phase 3 (CMIP3) and Coupled Model Intercomparison Project Phase 5 (CMIP5). The main components of the Klamath River Basin Study and their interaction with developed climate change scenarios are shown in Figure 4-1. The ensemble hybrid delta (HDe) period change method (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d) described in Chapter 3 was used to assess the impacts of climate change on demands. The future periods used for the Klamath River Basin Study are the 2030s and 2070s (represented as the mean over 2020–2049 and 2060–2089, respectively) and the historical baseline period used for the analyses is 1950–1999.

Some of the analyses described in this chapter are based on previous work done as part of Reclamation's West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). WWCRA is a component of the Department of the Interior WaterSMART Program that was implemented to meet requirements of the Secure Water Act (Public Law 111-11, Sections 9501-9510).[6]

[6] http://www.usbr.gov/WaterSMART/wcra/index.html

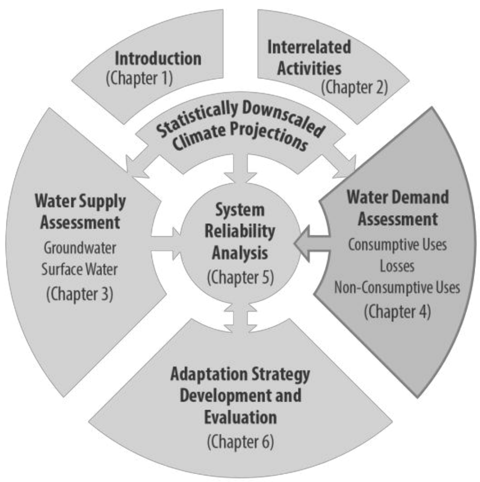

Figure 4-1. Overall approach of Klamath River Basin Study, highlighting Chapter 4

4.1.1 Description of Water Demands

Water demands are typically associated with one or more water uses that can be consumptive or non-consumptive. Consumptive water use results in a loss of water from the supply system, often associated with human activities. Examples of consumptive uses include manufacturing, agriculture, and food preparation where water is not returned to the supply system. Evaporation from water bodies such as reservoirs is another type of consumptive use that is more typically considered a loss. Non-consumptive uses are those which do not deplete the water supply. There are many types of non-consumptive uses; significant examples relevant to this study include hydropower generation, environmental resources, recreation, and aquaculture. Municipal and industrial (M&I) and rural domestic demands are typically comprised of both non-consumptive and consumptive uses. Another significant demand category relevant to the study is tribal demands, which are also comprised of both consumptive and non-consumptive uses.

Definition of Terms

Demand – Water needed to meet identified uses.

Consumptive Use – Water use resulting in a loss of available water supply, often associated with human activities.

Loss – Reduction of available water supply due to evaporation and operation inefficiencies.

Non-Consumptive Use – Water use not resulting in reduction of available water supply.

The focus of the Klamath River Basin Study is the assessment of current and future demands with respect to consumptive uses (both human-influenced and natural) and losses. Non-consumptive demands are either discussed qualitatively in this chapter or are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6.

4.1.2 Previous Studies

Many previous studies have quantified various types of water demand in all or part of the Klamath River Basin. Table 4-1 identifies the references that were reviewed in development of the water demands assessment. In the case of agricultural irrigation and reservoir evaporation, we utilized methods described by Reclamation (2014) in order to maintain consistency with approaches used in other western U.S. watersheds.

The following sections discuss current and future water demands, and detail how previous studies were used and whether the analysis was quantitative or qualitative.

Table 4-1. Summary of demand categories and related previous studies

Demand Categories	Primary Information Source(s)	Domain
Human Influenced Consumptive Uses		
Agricultural irrigation	Reclamation WWCRA (2014)	Western U.S.
		U.S. Counties
	HDR (2008)	Oregon
	CDWR (2009)	California
	Cuenca (1992)	Upper Klamath Basin (Oregon)
	Gannett et al. (2007)	Upper Klamath Basin
	Reclamation (2005b)	Klamath Project area
Municipal & Industrial	CDM (2010)	Klamath Falls, OR
	SHN (2004)	Hayfork, CA
	Pace (2011)	Weaverville, CA
	Pace (2004)	Weed, CA
	Tully and Young (2010) and Pace (2006)	Yreka, CA
	The USGS Water Use Program (http://water.usgs.gov/watuse/; Kenny et al., 2009)	U.S. Counties
	HDR (2008)	Oregon
	CDWR (2009)	California
Rural Domestic	USGS Water Use Program	U.S. Counties
Tribal	Interior and CDFG (2012)	

Table 4-1. Summary of demand categories and related previous studies

Demand Categories	Primary Information Source(s)	Domain
Other Consumptive Uses and Losses		
Wetlands	Stannard et al. (2013)	Upper Klamath Basin
	Mayer and Thomasson (2004)	Lower Klamath NWR
	Bidlake (2002)	Tule Lake NWR
Evaporation from lakes and reservoirs	Reclamation WWCRA (2014)	Western U.S.
	Bidlake (2000), Bidlake and Payne (1998), Janssen and Cummings (2007), and Stannard et al. (2013)	
Non-Consumptive Uses		
Environmental Resources	See Section 4.2.3.2, Environmental	
Hydropower	See Section 4.2.3.3, Hydropower	
Recreation	See Section 4.2.3.1, Recreation	
Aquaculture	See 4.2.3.4, Aquaculture	

4.2 Current Demands

Historical and current consumptive water uses and losses were quantified through findings from previous studies and model simulations and evaluated in order to compare with potential future changes due to climate change. Non-consumptive uses are briefly discussed; however, these uses are quantified in the modeling supporting the system reliability analysis in Chapter 5. Identified non-consumptive needs are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6. The current demands considered in this chapter are listed in Table 4-2 along with the sources or models used to provide an estimate for the Klamath River Basin Study. Each of the demands evaluated in this chapter, and the associated estimates used, are discussed in the sections that follow.

> **Current Human Influenced Consumptive Uses**
>
> Based on analyses supporting the Klamath River Basin Study, total consumptive water demand for human uses in the basin is about 800,000 acre-feet/year and about 98 percent of the total human influenced demand is for agricultural irrigation.

4.2.1 Human Influenced Consumptive Uses

Consumptive uses for human needs in the Klamath River Basin Study demands assessment have been quantified using a variety of existing sources as well as

model simulations. Table 4-2 summarizes the categories for which demands have been quantified, showing primary sources of data and models used.

One existing source of consumptive use information, which was used in conjunction with other sources described later, is the countywide USGS Water Use Program data. This is arguably the most comprehensive source of existing water use information for the study area (including both consumptive and non-consumptive uses). The most current data available are typically for 2005 and 2010, but more recent data were available in a few cases.

Current Human Influenced Consumptive Use Estimate Sources

Human influenced consumptive use estimates are based in part on USGS data, but this study uses WWCRA based model simulations for agricultural demands

Table 4-2. Summary of demand categories evaluated by the Klamath River Basin Study Assessment of Current and Future Water Demands and data and methods used

Demand Categories	Data Sources Used	Methods Used
Human Influenced Consumptive Uses		
Agricultural irrigation	Reclamation WWCRA (2014)	ET Demands Model (further described in corresponding section)
Municipal & industrial	Municipal water plans and USGS Water Use Program (see references in Table 4-1)	Statistical models and historical information
Rural domestic	USGS Water Use Program	Statistical models and historical information
Tribal	Addressed as part of agricultural, M&I, and Rural Domestic demand categories	
Other Consumptive Uses and Losses		
Wetlands	Stannard et al. (2013)	ET Demands Model and empirical relationships
Evaporation from lakes and reservoirs	Reclamation WWCRA (2014)	Complementary Relationship Lake Evaporation (CRLE) model

Included in Table 4-3 are 2005 USGS usage estimates for Siskiyou and Trinity Counties in California, Klamath County, Oregon, and the portion of Modoc County, California within the Klamath River Basin.[7] The total basin demand is approximately 1.2 million acre-feet per year (AFY). Note that Table 4-3 values are not all-inclusive since Del Norte and Humboldt Counties in the California portion of the basin are not included. Estimates for these counties are not

[7] http://water. usgs.gov/watuse/

included since only a very small portion of their water demands (estimated between 1 and 2 percent) occur within the basin. The in-basin demands for these counties are discussed later under the specific demand category discussions. Also note that the USGS data do not include reservoir evaporation. Additionally, the uses reported in Table 4-3 include both consumptive and non-consumptive components of these uses. For example, municipal and industrial (M&I) use includes water that eventually returns to the river system via a wastewater treatment plant.

Table 4-3. Summary of USGS 2005 Water Use Program estimates for the Klamath River Basin

Water Use Category (note: includes both consumptive and non-consumptive uses)	2005 Use (AFY)
Surface water irrigation	717,154
Groundwater irrigation	433,164
Municipal and industrial	18,204
Rural domestic	11,255
Livestock	2,903
Mining and industrial/commercial	2,868
Total (human influenced uses)	**1,185,548**

Source: USGS Water Use Program

The Klamath River Basin Study estimates of current human influenced consumptive uses in the watershed are based in part on the USGS Water Use Program data summarized above. However, in the case of agricultural irrigation demand (surface and groundwater), this study utilizes model simulations of agricultural water requirements following the approach of Reclamation's West Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). In the case of M&I and rural domestic water uses, more current (2010) estimates were made based on historical population trends. Also, the study focuses only on the consumptive portion of these demands, which is assumed to be 40 percent for both M&I and rural domestic demands and comprised of landscape irrigation (refer to Section 4.2.1.2, Municipal and Industrial).

Estimated current consumptive uses (including human influenced uses, wetland ET, and reservoir evaporation losses) by the Klamath River Basin Study are summarized in Table 4-4. These are estimated basin-wide uses that are the basis for assessment of projected changes in consumptive uses and losses for the two future time periods considered in this study, the 2030s and 2070s. Respective sections of this chapter provide details behind these estimates and the associated assumptions made. Note that the estimated reported M&I and rural domestic consumptive uses (see Table 4-4) are approximately 40 percent of the values reported by the USGS Water Use Program (see Table 4-3), which supports the

assumption by the Klamath River Basin Study regarding the consumptive portion of total M&I and rural domestic demand.

Table 4-4. Estimated current basin-wide consumptive uses and losses as computed by the Klamath River Basin Study

Basin Wide Consumptive Uses and Losses	Estimated Mean Annual Quantity (AFY)
Agricultural irrigation (NIWR)	755,734
Municipal and industrial	8,801
Rural domestic	4,537
Subtotal for Human Influenced Consumptive Use	**769,072**
Wetland ET	1,089,061
Reservoir and lake evaporation	181,297
Total Consumptive Uses and Losses	**2,039,430**

4.2.1.1 Agricultural Irrigation

Irrigation of croplands is by far the largest human influenced consumptive use in the Klamath River Basin, 97 percent[8] according to the USGS Water Use Program estimates (which include conveyance and on-farm losses) and approximately 98 percent[9] according to the Klamath River Basin Study estimates (which do not include conveyance and on-farm losses). Agricultural irrigation use typically includes crop demands, conveyance losses, and on-farm losses. Conveyance and on-farm losses are a function of methods employed to convey water to the croplands (open channels, pipe, etc.) and to apply irrigation water (flood, sprinklers, etc.). Given the numerous variables associated with conveyance and on-farm losses, these losses were not calculated in this study.

> **ET Demands Model Methodology**
>
> The model calculates historical and future daily net irrigation water requirements using the FAO-56 dual crop coefficient method with crops, temperature, precipitation, wind, and soil inputs. Solar radiation and humidity are estimated from daily minimum and maximum temperature inputs.

Crop demands are consumptive. Conveyance and on-farm losses can be consumptive or non-consumptive. Examples of non-consumptive conveyance and on-farm losses include field runoff and deep percolation, since associated water generally returns to the supply system. An example of a conveyance or on-farm loss that is

[8] Computed as sum of 717,154AFY and 433,164AFY, divided by 1,185,548AFY (refer to Table 4-3).
[9] Computed as subtotal for human influenced consumptive uses 755,734AFY, divided by 769,072AFY (refer to Table 4-4).

consumptive is evapotranspiration by natural vegetation on farm lands or in and around canals.

This study focuses on the crop demands, or crop net irrigation water requirement (NIWR). NIWR is equal to the total crop demand minus that amount of the crop demand that is met by precipitation, i.e., effective precipitation (P_e). NIWR does not include conveyance or on-farm losses. Crop water demand is a function of evapotranspiration (ET), which is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Allen et al., 1990). Crop water demand also does not include conveyance or on-farm losses.

Current NIWR estimates have been developed for this study. A discussion of recent irrigation demand estimates is presented first, followed by a discussion of the developed NIWR estimates.

Current Agricultural Irrigation Demand

Agricultural irrigation demands, in the form of net irrigation water requirement (NIWR), were simulated by the ET Demands model using current cropping data and average climate conditions for the period 1950–1999.

Recent Irrigation Estimates by Others

Estimates by others are presented as background information and for comparison to those developed in the Klamath River Basin Study. As discussed previously, the USGS estimates that total irrigation water use for the basin in 2005 was 1,150,318 AF, including 717,154 AF from surface water sources and 433,164 AF from groundwater sources (Kenny et al., 2009). These estimates include irrigation of golf courses, parks, nurseries, cemeteries, and other self-supplied landscape-watering uses. The USGS estimates also include conveyance and on-farm water losses. Detailed information on how the USGS developed the 2005 irrigation estimates is provided in Dickens et al. (2011).

The CDWR estimates crop irrigation demands annually for the California portion of the Klamath River Basin (the Klamath Upper and Lower Planning Sub-area).[10] The CDWR estimates include NIWR and total water applied, which includes on-farm losses but not conveyance losses. The reported 2010 estimates for the California portion of the basin are 347,672 AF of NIWR and 482,504 AF total water applied (Coombe, 2013). It is estimated that approximately 62 percent of the total demand is met with surface water and 38 percent is met with groundwater sources.

The OWRD's recent Statewide Water Needs Assessment (HDR, 2008) includes a 2010 agricultural irrigation water use estimate for Klamath County, Oregon,

[10] http://www.water.ca.gov/landwateruse/anlwuest.cfm

which represents the approximate Oregon portion of the basin. The estimate is 730,000 AF and includes both on-farm and conveyance losses.

The sum of CDWR and OWRD estimates (1,212,504 AF) is greater than, though comparable to, the USGS estimate for total irrigation (1,150,318 AF). It is assumed the discrepancies are associated with which loss estimates were included and how they were estimated.

Estimation of Net Irrigation Water Requirements

Current and future NIWR estimates were developed for this study following the methods established by Reclamation's WWCRA. Brief descriptions of these methods follow and more detailed discussions are contained in Reclamation (2014).

The current or baseline irrigation water demand estimates developed for this study are based on the most recent available crop data and climate conditions during the historical baseline period 1950 through 1999. Crop types and quantities reported for 2009 were provided by the Klamath Basin Area Office for Reclamation's Klamath Project lands, and crop data for the remainder of the basin were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service as reported for 2010.[11] The 1950 through1999 climate data used are from the same published data set by Maurer et al. (2002) discussed in Chapter 3. The values used from this data set were adjusted based on historical observations from 13 weather stations located near the irrigated crop areas to remove any biases that may exist between the gridded meteorological dataset (Maurer et al., 2002) and these point observations.

NIWR estimates were calculated for each of the basin's twelve Hydrologic Unit Code eight-digit level drainage areas (HUC8 sub-basin). The HUC8 sub-basins are shown in Figure 4-2. The map also includes the estimated number of irrigated acres by HUC8 sub-basin. Point locations in the figure represent corresponding weather stations used to support the modeling effort, including those used for removing biases in the gridded meteorological dataset and those used for estimating dewpoint and windspeed across the HUC8 sub-basins. Table 4-5 provides additional details for some of these features. A full summary of weather station information is provided in Appendix C, Section 2.0. Appendix C, Section 3.0 summarizes the estimated percentage of crop acreage within each HUC8 sub-basin according to crop type.

[11] http://www.nass.usda.gov/research/Cropland/SARS1a.htm

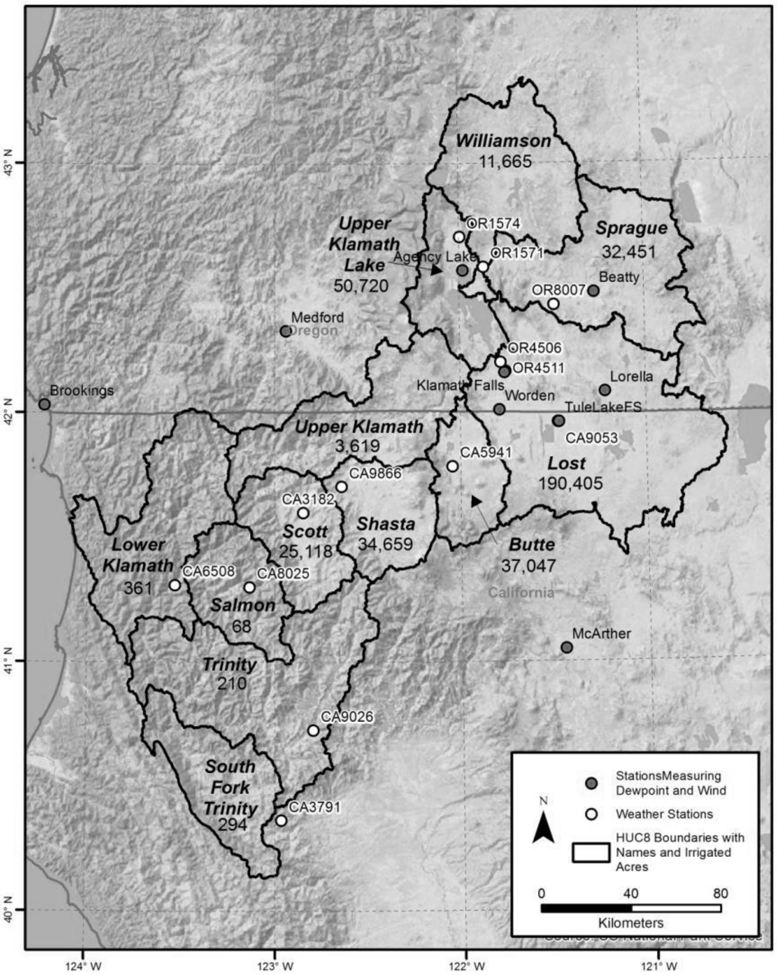

Figure 4-2. Klamath River Basin – HUC8 Sub-basins, irrigated acres, and weather stations used to simulate baseline and projected irrigation demands

Table 4-5. Irrigated land totals and weather stations associated with HUC8 sub-basins

HUC8 Name / Number	Weather Station Name(s)	Irrigated Acres
Williamson / 18010201	Chiloquin	11,665
Sprague / 18010202	Sprague River 2 SE	32,451
Upper Klamath Lake / 18010203	Chiloquin NW	50,720
Lost River / 18010204	Tule Lake and Klamath Falls	190,405
Butte /18010205	Mount Hebron	37,047
Upper Klamath / 18010206	Klamath Falls 2 SSW	3,619
Shasta /18010207	Yreka	34,659
Scott / 18010208	Fort Jones	25,118
Lower Klamath / 18010209	Orleans	361
Salmon / 18010210	Sawyers Bar	68
Trinity / 18010211	Trinity River Hatchery	210
South Fork Trinity / 18010212	Harrison Gulch	294
Total Irrigated Acres		**386,616**

Estimates of NIWR were developed using the ET Demands model, originally developed by the University of Idaho, Nevada Division of Water Resources, and the Desert Research Institute (DRI). Recent modifications to the model for WWCRA applications were made through a collaborative effort by Reclamation, DRI, and the University of Idaho (Reclamation, 2014).

The ET Demands model is based on the Penman Monteith (PM) dual crop coefficient method (Allen et. al, 1998). The American Society of Civil Engineers (ASCE) has adopted the FAO-56 PM equation as the standardized equation for calculating reference ET (ET_o) (ASCE, 2005). The short grass reference crop version of the PM equation was used to be consistent with previous Reclamation work.

By using the PM dual crop coefficient method rather than a single crop coefficient approach, transpiration and evaporation are accounted for separately to better quantify evaporation from variable precipitation and simulated irrigation events. This also allows accounting of winter soil moisture conditions, which can be a significant factor when estimating early irrigation season NIWR. The dual crop coefficient method provides a robust means for estimating NIWR based on continuous accounting of soil moisture balance.

The ET Demands model first calculates daily ET_o for each HUC8 sub-basin as a function of maximum and minimum daily air temperature (T_{max} and T_{min}) from the 1950–1999 climate data set mentioned above. The PM equation variables of vapor pressure, solar radiation, and wind speed are empirically estimated as described in Reclamation (2014) per the methods recommended by ASCE (2005). Figure 4-3 shows the spatial distribution of mean daily historical baseline

temperature, precipitation, dewpoint depression,[12] and wind speed (lower right) values used in the model. The historical baseline precipitation and temperature values for each HUC8 sub-basin are included in the model results summary tables provided in Appendix C, Section 1.0. The Figure 4-3 windspeed and dewpoint depression panels include the point locations of weather stations used as the basis for estimating these values for HUC8 sub-basins (see also Figure 4-2 and Appendix C, section 2.0).

Figure 4-3 illustrates warm to cool mean annual temperatures from west-southwest to northeast, respectively, while precipitation varies from moderately high to low amounts from southwest-central to northeast, respectively. The spatial distribution of mean annual dewpoint depression clearly shows northeast areas are more arid while southwest-central areas are more humid. The spatial distribution of mean annual wind speed generally exhibits lower wind speed in west and southwest areas, with higher wind speed in the northeast portion of the basin.

Weighted average soil conditions (including allowable water content and percent clay, silt, and sand) for the irrigated lands in each HUC8 sub-basin were input to the ET Demands model. The soils information is based on data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (USDA-SCS, 1991). The soil parameters affect the estimation of irrigation scheduling, evaporation losses from soil, deep percolation from root zones, antecedent soil moisture condition, and runoff from precipitation.

[12] Dewpoint depression is equal to T_{min} minus dewpoint temperature and is used to estimate vapor pressure or humidity values.
[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

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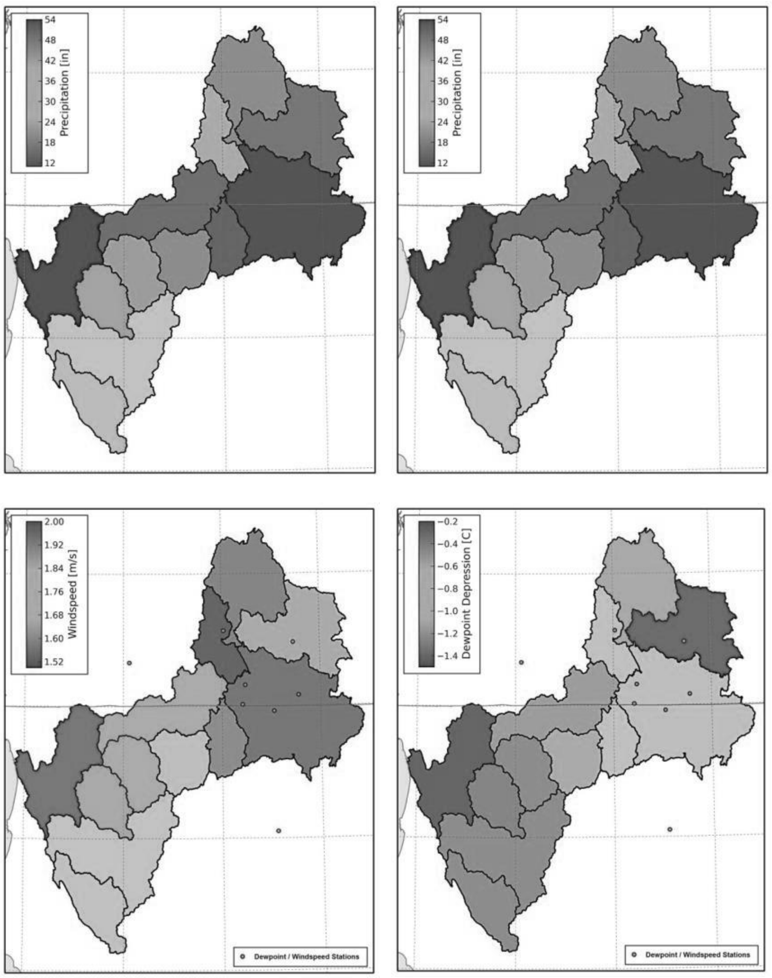

Figure 4-3. Spatial distribution of historical baseline (1950–1999) mean annual temperature, precipitation, windspeed, and dewpoint depression

The daily net or actual ET (ET_c) is then calculated as a function of the two primary crop coefficients and a crop stress coefficient. ET_c for all crop types within a given HUC8 was estimated as follows:

$$ET_c = (K_s K_{cb} + K_e) ET_o$$

where ET_o is the ASCE-PM grass reference ET, K_{cb} is the basal crop coefficient, K_e is the soil water evaporation coefficient, and K_s is the stress coefficient. K_{cb} and K_e are dimensionless and range from 0 to 1.4. Daily K_{cb} values over a season, commonly referred to as the crop coefficient curve, represent impacts on crop ET from changes in vegetation phenology, which can vary from year to year depending on the start, duration, and termination of the growing season, all of which are dependent on temperature. K_e is a function of the soil water balance in the upper 0.1 meter of the soil column, since this zone is assumed to be the only layer supplying water for direct evaporation from the soil surface. K_s ranges from 0 to 1, where 1 equates to no water stress, and is also dimensionless. A daily soil water balance for the simulated effective root zone is required and computed in ET Demands to calculate K_s. In the case of computing the ET_c and NIWR, K_s is generally 1 but can be less than 1 in the winter if precipitation is low and winter surface cover is specified to be anything other than bare soil, such as mulch or grass.

Values of K_{cb} for a given crop vary seasonally and annually to simulate plant phenology as impacted by solar radiation, temperature, precipitation, and agricultural practice. Seasonal changes in vegetation cover and maturation are simulated in the ET Demands model by each crop specific K_{cb} as a function of air temperature. This is expressed in terms of cumulative growing degree days (GDD). After planting of annuals or the emergence of perennials, the value of K_{cb} gradually increases with increasing temperatures until the crop reaches full cover. Once this happens, and throughout the middle stage of the growing season, the K_{cb} value is generally constant or is reduced due to simulated cuttings and harvest. From the middle stage to the end of the growing season the K_{cb} value reduces to simulate senescence. GDD is calculated in the ET Demands model by three different methods as described in Reclamation (2014). The GDD equations' constants were calibrated based on historical data (green-up or planting, timing of full cover, harvest, and termination dates).

Having the ability to simulate year to year variations in the timing of green-up or planting, timing of effective full cover, harvest, and termination, is necessary for integrating the effects of temperature on growing season length and crop growth and development, especially under changing climate scenarios.

The NIWR rate or depth is calculated in the ET Demands model by factoring in P_e (NIWR = $ET_c - P_e$). P_e is calculated as a function of daily precipitation (from the climate data set), antecedent soil moisture, and precipitation runoff. Soil moisture is a function of the moisture holding capacity of the weighted average soil type input to the model for each HUC8 sub-basin. Precipitation runoff is calculated based on daily precipitation using the NRCS curve number method (USDA-SCS, 1972).

Simulation of irrigation events by the ET Demands model occurs when the crop root zone moisture content drops to the crop specific maximum allowable depletion threshold. Irrigations are specified to fill the root zone by the difference between field capacity[13] and the cumulative soil moisture depletion depth amount.

The NIWR and ET_c rates for each crop within a given HUC8 sub-basin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 sub-basin and all crop values are summed to calculate weighted average HUC8 sub-basin NIWR and ET_c rates, as shown in the equation below.

$$HUC8\ subbasin\ rate\ = \sum_{i=1}^{i=n} crop\ ratio\ i * crop\ rate\ i$$

The product of the weighted average NIWR and the total irrigated acreage yields the NIWR volume for each HUC8 sub-basin in acre-feet. A similar approach is used to calculate the ET_o, ET_c, and NIWR estimates for the entire Klamath River basin where the ratios of sub-basin to basin irrigated acres are applied to the sub-basin values and the average of the weighted values is calculated. Crop types and corresponding percentages of total crop acreage by HUC8 sub-basin are provided in Appendix C, Section 3.0.

The ET Demands model results for baseline conditions include ET_o, ET_c, NIWR rate, and NIWR volume for each HUC8 sub-basin. The annual average values for 1950–1999, which represent the historical baseline or current conditions for the purpose of this study, are summarized in Table 4-6. Graphical representations of these values are provided in Figure 4-4. Spatial distributions of ET_o, ET_c, and NIWR depth ranges from 41 to 51, 29 to 52, and 18 to 37 inches per year, respectively, with higher rates occurring in the northeast portion of the basin where growing season air temperature, solar radiation, and dewpoint depression are significantly larger relative to the southwest-central portion of the basin. NIWR volumes range from 197 AFY in the Salmon HUC8 sub-basin, where there is very little irrigated land, to 329,469 AFY in the Lost River HUC8 sub-basin where the majority of Reclamation's Klamath Project irrigated lands are located.

[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

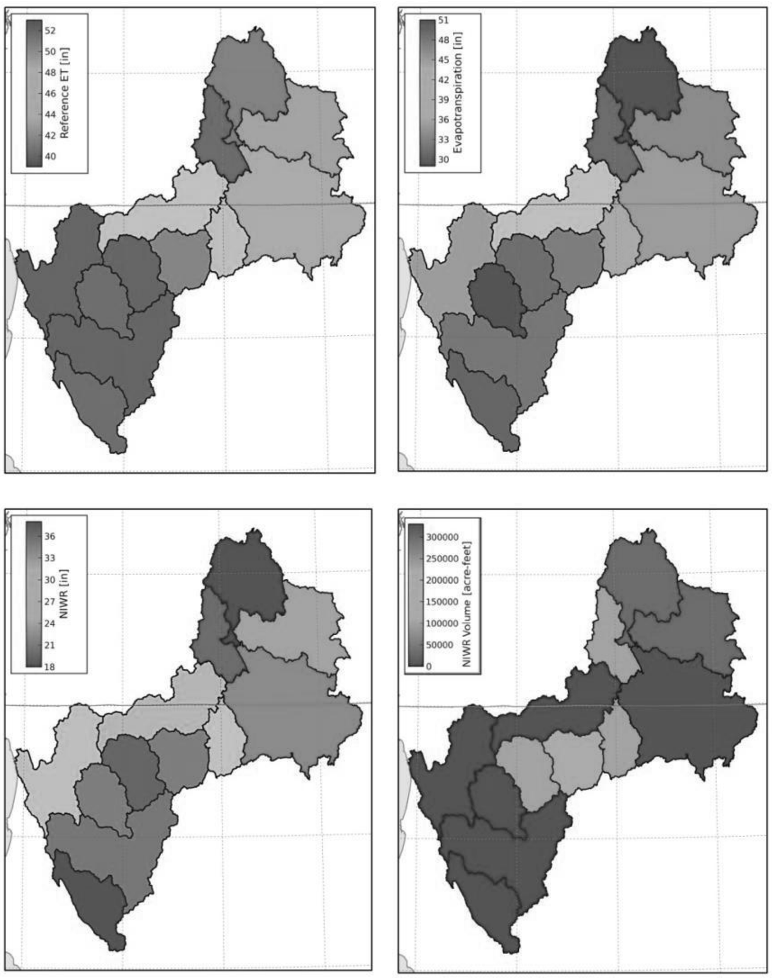

Figure 4-4. Spatial distribution of baseline reference evapotranspiration, crop evapotranspiration, net irrigation water requirement depth, and NIWR volume

Table 4-6. Summary of baseline reference evapotranspiration, crop evapotranspiration, and net irrigation water requirement rates and volumes

HUC Sub-basin	ET_o (in/year)	ET_c (in/year)	NIWR Rate (in/year)	NIWR Volume (AFY)
Williamson	40.8	29.4	18.0	17,513
Sprague	42.3	29.5	20.4	55,216
Upper Klamath Lake	39.9	30.4	18.7	79,101
Lost River	43.3	34.1	20.2	329,469
Butte	46.9	36.5	27.2	83,976
Upper Klamath	45.4	40.9	30.7	9,255
Shasta	50.5	47.9	35.1	101,460
Scott	52.3	49.0	36.8	77,114
Lower Klamath	52.2	44.6	29.5	887
Salmon	52.0	50.6	35.0	197
Trinity	52.3	48.6	35.9	628
South Fork Trinity	51.8	49.6	37.4	917
Averages & Total NIWR Vol.	**47.5**	**40.9**	**28.7**	**755,734**

Notes: ETo = reference evapotranspiration; ETc = crop evapotranspiration; NIWR = net irrigation water requirement

Table 4-7 provides a summary of the basin total NIWR from Table 4-6 and the previous irrigation estimates by USGS, CDWR, and OWRD. As discussed previously, the USGS and OWRD estimates include conveyance and application losses; the CDWR estimate includes application losses; and the USGS estimate includes irrigation demands for other uses in addition to agricultural irrigation (e.g., golf courses, parks, etc.). Depending on local conditions, significant conveyance and application losses are considered consumptive uses when providing water sources for riparian and wetland plants and sources of evaporation.

The ratio of the basin study estimate (755,734) to the USGS estimate (1,150,318) implies the overall average efficiency of the irrigation systems is approximately 66 percent, which is reasonable. The USGS estimate (1,150,318) is within 5.1 percent of the sum of the QWRD and CDWR estimates (730,000 + 482,504 = 1,212,504).

Table 4-7. Summary of irrigation demand estimate developed for this study and previous estimates by others

Description	Annual Volume (AFY)
Basin total crop net irrigation water demand estimated in Klamath River Basin Study	755,734
Basin total irrigation demand from 2005 USGS Water Use Program	1,150,318
OWRD 2010 estimate of crop irrigation demand for the Oregon portion of the basin	730,000
CDWR 2010 estimate of crop irrigation demand for the California portion of the basin	482,504

4.2.1.2 Municipal and Industrial

This category includes water demands that are met by public water supply systems that range in size from 15 connections[14] to many thousands of connections. The estimates are typically based on the supplier's production quantities, which include water delivered to customers plus leakage and other unaccounted for water. M&I customers include domestic households, industrial facilities, and commercial businesses.

Basin-wide total M&I use, shown in Table 4-3, is 18,204 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, which are entirely within the Klamath River Basin. Modoc, Humboldt, and Del Norte Counties each have small fractions within the Klamath River Basin. Most of the Humboldt and Del Norte County systems serve tribal communities. Note that within the California portion of the basin there is one small M&I system in Modoc County; there are four small systems in Humboldt County, and seven small systems in Del Norte County. Information on these California county systems is discussed later in this section.

Per capita total use estimates for the three counties entirely within the Klamath River Basin were calculated from the USGS data by dividing annual use by the reported population served. These estimates are summarized in Table 4-8.

Table 4-8. Per capita total M&I water use estimates from USGS 2005 data (including consumptive and non-consumptive portions)

County, State	Per Capita Rates (gpcd)
Siskiyou , California	468
Trinity , California	146
Klamath , Oregon	188

Source: USGS

[14] The Safe Drinking Water Act, Section 1401(4) defines a public water system as that delivering water for human consumption to not less than 15 service connections or 25 regularly served persons.

The Siskiyou County per capita total M&I water use reported in 2005 by the USGS is much higher than for Klamath County and Trinity County. Further, review of near current total M&I use from recent planning studies for Weed and Yreka suggest this value to be outside the estimated range for the two largest municipalities in Siskiyou County.

Water plans were reviewed for the four largest municipalities in the Klamath River Basin which include Weed and Yreka in Siskiyou County, California, Weaverville in Trinity County, California, and Klamath Falls in Klamath County, Oregon. Most of the entities that provide M&I service to the smaller municipalities in Del Norte, Humboldt, and Modoc Counties were contacted for recent water use data, as they do not have municipal water plans. These include Willow Creek, Orleans, and Hoopa in Humboldt County, California, Newell in Modoc County, California, and Klamath in Del Norte County, California. Current annual water use for these municipalities is summarized in Table 4-9. Similar to uses identified by municipal water plans, these uses include both consumptive and non-consumptive components.

It should be noted that reported M&I uses typically include both consumptive and non-consumptive components. In the Klamath River Basin Study, those reported M&I uses that include both components are described as total M&I use. This study focuses only on the consumptive portion of M&I use and assumes that 40 percent of total M&I use is consumptive and is used for landscape irrigation, with the remaining 60 percent becoming wastewater effluent. In this section we distinguish between total M&I use and consumptive M&I use, where practicable.

M&I and Rural Domestic Consumptive Use

Approximately 75 percent of the M&I demand within the Klamath River Basin is from the four largest municipalities (Klamath Falls, OR; Weed, CA; Yreka, CA; Weaverville, CA). Annual rural domestic uses represent approximately 0.4 percent of total basin demand.

Based on Mayer et al. (1999) and given that the majority of the basin's population is located in warmer-drier areas, it appears 40 percent is a reasonable average value for the basin. Mayer et al. (1999) reports the findings of a residential water use study that included 1,188 households in 12 North American cities. The reported range of outdoor use as the percentage of total use is 22 to 67 percent, with a range of 22 to 38 percent for wetter climates. Also, the U.S. Environmental Protection Agency WaterSense Program website[15] reports that one-third of U.S. residential water use is for landscape irrigation.

[15] http://www.epa.gov/WaterSense/pubs/outdoor.html

Table 4-9. Summary of total M&I use for significant municipalities

Location	Annual Use (AFY)	Per Capita Demand (gpcd)	Reference
Klamath Falls, OR (Klamath County)	9,428 (2010 est)	167 (1998-2007est)	CDM (2010)
Yreka, CA (Siskiyou County)	2,243 (2010 est)	280-325 (2011 est)	Pace (2006), Tully and Young (2011)
Weed, CA (Siskiyou County)	994 (2010 est)	NA	Pace (2004)
Weaverville, CA (Trinity County)	841 (2010 est)	NA	Pace (2011)
Total of Above Annual Demands	**13,506**[16]		
Newell, CA (Modoc County)	188	194	2003 CDWR funding application (Hammond Engineering, 2001)[17]
Willow Creek, CA (Humboldt County)	767	401	Personal communication[18]
Hoopa, CA (Humboldt County)	565	168	Personal communication[19]
Orleans, CA (Humboldt County)	153 (OCSD) 50 (OMWC)	319 (OCSD) 529 (OMWC)	Personal communication[20]
Klamath, CA (Del Norte County)	166 (est)	150 (est)	Personal communication[21]
Total of Above Annual Demands	**1,889**		

Comparison of the total for the four large municipalities (13,506 AF) to the USGS reported 2005 M&I total (18,204 AF) indicates approximately 75 percent of the M&I demand within the majority of the basin (Klamath County, Oregon and Trinity and Siskiyou Counties in California) is from these municipalities and the other approximately 25 percent is made up by the smaller M&I systems. The Klamath River Basin Study estimates 2010 total M&I use as the sum of use in

[16] Compare with USGS total demand for Klamath, Siskiyou, and Trinity Counties of 18,204 AFY. The comparison shows that demands from the four major municipalities comprise about 75 percent of the total demand in these three counties.

[17] CDWR funding application reports an annual use of 188 AFY and a 1999 service population of 866. This yields a per capita demand rate of 194 gpcd.

[18] Mr. Lonnie Danel, Administrator (personal communication, November 8, 2013). The 2012 approximate annual use for the Willow Creek Community Service District is 767 AF. Based on the 2010 census population for Willow Creek (1,710) this use yields a per capita demand of 401 gpcd.

[19] According to Mr. Murphy Lott, Operator for Hoopa Public Utilities District, Humboldt County, California (personal communication, November 12, 2013), the 2012 total use for the District's service area was approximately 565 AFY. Based on the reported service area population of approximately 3,000, the per capita average demand is 168 gpcd.

[20] Orleans, California in Humboldt County is served by two public water systems. Debbie Mace of the Orleans Community Service District (OCSD) reports (personal communication, December 5, 2013) approximate annual total M&I usage is 153 AFY serving a population of 430. This equates to a per capita demand of 319 gpcd. Jim Slusser of the Orleans Mutual Water Company (OMWC) reports (personal communication, December 5, 2013) approximate annual total usage is 50 AFY serving a population of 85. This equates to a per capita demand of 529 gpcd.

[21] Ms. Jan Chinook (personal communication, November 12, 2013) with the Klamath, California Chamber of Commerce reports there are seven public water systems serving this community in Del Norte County. The approximate population served by these systems is reported to be 985. Three of seven operators that were successfully contacted reported their systems are not metered. Given the lack of data and the generally transient service population, per capita demand was assumed (150 gpcd) to estimate an annual total M&I use of 166 AFY.

Klamath, Siskiyou, and Trinity Counties, plus uses identified in the small municipalities of Modoc, Humboldt, and Del Norte Counties.

As stated above, an estimated 40 percent of total M&I use is for landscape irrigation. This fraction is considered 100 percent consumptive. The remaining 60 percent of the total M&I use is considered non-consumptive and is assumed to return to receiving waters as wastewater effluent. The computed basin-wide M&I consumptive use of 8,801 AFY is the baseline M&I consumptive use for the Klamath River Basin Study (see Table 4-4). The M&I uses that comprise the Klamath River Basin Study estimate of basin-wide current annual consumptive use are provided in Table 4-10.

Table 4-10. Summary of total and consumptive M&I uses for the Klamath River Basin Study

Location	Annual M&I Use (AFY)
Klamath County	9,736
Siskiyou County	7,286
Trinity County	3,093
Small municipalities of Modoc, Humboldt, and Del Norte Counties	1,889
Basin Wide Total M&I Use	22,004
Basin Wide Consumptive M&I Use	8,801

4.2.1.3 Rural Domestic

The estimate of basin-wide rural domestic use shown in Table 4-3 is 11,255 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, plus a portion of the reported demand for Modoc County. The Modoc County estimate was calculated as the product of the reported use for the county and the ratio of the estimated population within the basin to the total county population. It is assumed the limited number of rural domestic water users in the portions of the basin in the counties of Del Norte and Humboldt in California and Lake and Jackson in Oregon are negligible. Based on these data and excluding hydropower and lake and reservoir evaporation, annual rural domestic uses represent approximately 0.4 percent of total basin demand. Note that, similar to M&I use, the rural domestic use reported by the USGS includes both consumptive and non-consumptive components. The Klamath River Basin Study assumes that 40 percent of total rural domestic use goes to landscape irrigation and is entirely consumed. (See discussion and references to Mayer et al. (1999) and the WaterSense program[22] above under Section 4.2.1.2, Municipal and Industrial.) The remaining 60 percent of the total rural domestic use is assumed to return to receiving waters via wastewater effluent (i.e., septic systems). This study differentiates between total

[22] http://www.epa.gov/WaterSense/pubs/outdoor.html

rural domestic use, which includes both consumptive and non-consumptive components, and consumptive rural domestic use.

The total rural domestic per capita demands reported by USGS for 2005 range from 106 to 190 gpcd. The 2005 county rates and average for all but Humboldt and Del Norte counties are summarized in Table 4-11. Total rural domestic uses summarized here may be compared with total M&I demands provided in Tables 4-8 and 4-9 in terms of both per capita demands and mean annual total use volumes. Mean annual total rural domestic demands were computed based on the product of per capita demand and estimated population. Generally rural domestic demands are less than M&I demands, except for Trinity County where estimated rural domestic demand rates are higher than M&I. Table 4-9 also provides the estimated baseline consumptive rural domestic use for the Klamath River Basin Study.

Table 4-11. Summary of 2005 county rural domestic use

County	Annual Rural Domestic Use (AFY)	Per Capita Demand (gpcd)
Siskiyou County, California	6,621	190
Trinity County, California	1,040	158
Klamath County, Oregon	3,481	150
Modoc County, California	201	180
Total Rural Domestic Use	11,343	
Consumptive Rural Domestic Use	**4,537**	

4.2.1.4 Tribal

This discussion addresses the consumption portion of water demands associated with the six federally recognized tribes that inhabit the Klamath River Basin: The Klamath Tribes, Quartz Valley Indian Community, Karuk Tribe, Hoopa Valley Tribe, Yurok Tribe, and Resighini Rancheria. Members of these tribes live along different reaches of the Klamath River and in different areas of the basin. Table 4-12 provides a summary of the Klamath basin Native Americans by culture, recognized representative tribal government, and the general location of each tribe in the Klamath basin (taken from Table 1-1, North State Resources, Inc., 2012). The Klamath Tribes live in the Upper Klamath Basin and the other five tribes are in the Lower Klamath Basin.

Tribal Water Demands

Tribal trust resources and associated adjudicated and non-adjudicated water rights are described in this section. The needs of fish and wildlife for water are further described in Section 4.2.3.2, Environmental Resources.

Tribal water uses are unique because the associated water rights are considered trust resources.[23] Tribal domestic and industrial water uses are included in the quantification of municipal and industrial demands as well as rural domestic uses summarized above. There are also inter-relationships between tribal water demands and other non-consumptive water use categories (e.g., environmental and ceremonial uses). Critical water-related trust resources associated with instream flow needs and lake levels to support hunting, trapping, gathering, and other cultural practices are briefly described in Section 4.2.3.2, Environmental Resources. However, instream flow uses are incorporated in the Klamath River Basin Study through development of measures which are used to evaluate the impacts of climate change and implementation of adaptation strategies (refer to Chapters 5 and 6).

The federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. The tribes have reserved rights to water according to the Winters Doctrine of 1908. Additionally, the Interior Solicitor's Office stated that "Reclamation is obliged to ensure that project operations not interfere with the Tribes' senior water rights" (Interior, Office of the Solicitor, Pacific Southwest Region, 1995). And, absent a "completed adjudication or other determination of the senior water rights," projects must be "operated on the best available information" (Interior, Office of the Solicitor, Pacific Southwest and Northwest Regions, 1997). The same recognition is extended to other resources such as vegetation and wildlife.

With the exception of the Klamath Tribes, tribal water rights are not officially recognized (adjudicated) by California and Oregon. Oregon's Klamath Basin Adjudication process reached the end of its "administrative" phase in March 2013, and the OWRD reached its Final Order of Determination generally confirming the senior water rights of the Klamath Tribes. In general, tribes' water rights claims seek to assure adequate quantities of good quality water to maintain tribal trust resources including fish, instream flows, groundwater, minerals, and land as well as cultural values, which may be described as traditional religious practices, traditional food preparation, trade and barter of goods, and other practices that reinforce personal and tribal identity (North State Resources, Inc., 2012).

Table 4-12. Klamath Basin Native American peoples

Klamath Basin Native American Cultures	Recognized Representative Tribal Government	General Location of Tribe in the Klamath Basin
Yurok	Yurok Tribe Resighini Rancheria	Lower Klamath River Lower Klamath River

[23] Indian trust resources consist of certain real property, natural resources, and related rights, held in trust by the federal government for federally recognized Indian Tribes or individual Indians.

Hupa	Hoopa Valley Tribe	Lower Trinity River
Karuk	Karuk Tribe Quartz Valley Indian Community	Middle Klamath River Salmon River Scott River
Shasta (Wairuhikwaiiruka/Kammatwa)	Quartz Valley Indian Community	Scott River Shasta River Upper Middle Klamath River
Modoc	Klamath Tribes	Upper Klamath Basin
Klamath	Klamath Tribes	Upper Klamath Basin
Snake (Yahooskin)	Klamath Tribes	Upper Klamath Basin

Source: North State Resources, 2012

A portion of the adjudicated and non-adjudicated water rights of the tribes are for agricultural purposes. This consumptive use is addressed by Section 4.2.1.1, Agricultural Irrigation, which identifies the NIWR for existing crops within the basin. These demands are not differentiated between tribal and non-tribal uses.

Primary references for this and additional information related to tribal trust resources include the Klamath Facilities Removal Final Environmental Impact Statement/Environmental Impact Report (Interior and CDFG, 2012), the Trinity Mainstem Fishery Restoration Environmental Impact Statement/Environmental Impact Report (Interior et al., 2000) and the North State Resources, Inc. (2012) report, supporting the Secretarial Determination Overview Report.

4.2.1.5 Livestock
Livestock water use is included in the USGS Water Use Program estimates. However, because water use by livestock comprises only 0.2 percent of total estimated basin water use and is not likely to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

4.2.1.6 Mining and Commercial/Industrial
Mining and self-supplied commercial/industrial use is included in the USGS Water Use Program estimates. However, because this consumptive use comprises only 0.2 percent of total estimated basin water use and is not expected to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

4.2.2 Other Consumptive Uses and Losses
This section quantifies current losses associated with evaporation at the Klamath River Basin's primary lakes and reservoirs and evapotranspiration by emergent wetlands. Losses result in a reduction of water supply and are therefore included in the assessment of water supply and demand with the intent to quantify current water supply shortages.

4.2.2.1 Wetlands

This section briefly summarizes the estimation of current wetland ET used for the Klamath River Basin Study, using findings from Stannard et al. (2013). Additional work by Mayer and Thomasson (2004) was used for verification of estimated current wetland ET. Additional work by Bidlake (2002) over the more focused region of Tule Lake NWR was also reviewed in support of estimated wetland.

The Klamath River Basin Study estimates mean annual wetland ET over 341,154 acres of wetlands estimated by the National Wetland Inventory for emergent wetlands.[24] Wetland ET volume is based on work by Stannard et al. (2013), who found that during the average 190-day alfalfa-growing season wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. Estimates of average daily alfalfa and pasture ET were computed by the ET Demands model. For ET Demands model simulations, daily ET for multiple crops was computed for HUC8 sub-basins within the Klamath River Basin, similar to the approach taken by Reclamation (2014) in the West-Wide Climate Risk Assessment. Alfalfa and pasture ET computed by HUC8 sub-basin were used to estimate wetland ET. Use of the ET Demands model for these values, as opposed to alfalfa ET and pasture ET reported by Stannard et al. (2013), allows for direct comparison of the consumptive uses quantified by this study and also allows for evaluation of projected changes in wetland ET in a changing climate. Current mean annual wetland ET, based on estimates of alfalfa and pasture ET using the ET Demands modeling approach described above, is approximately 1,089,061 AFY (averaging wetland ET based on each of alfalfa ET and pasture ET). Estimates of current wetland ET by this study corroborates with the findings of both Stannard et al. (2013) and Mayer and Thomasson (2004), as shown in Table 4-13 in which current wetland ET in units of AFY were computed based on reported ET rates and the same estimated wetland area. This study's estimate of mean annual wetland ET is included in the overall estimate of current water demands provided in Table 4-4. It should be noted that the ET Demands model was not configured to include wetlands ET. However, future research involving the ET Demands model may involve determining model coefficients for wetland vegetation.

[24] http://www.fws.gov/wetlands/

Table 4-13. Comparison of average annual current wetland ET from available sources

Source of Wetland ET Estimate	Average Annual Current Wetland ET (AFY)	ET Rate (ft/yr)
Mayer and Thomasson (2004)	1,040,910	3.05
Stannard et al. (2013)	1,049,862	3.08
Klamath River Basin Study	1,089,061[25]	3.31

Mayer and Thomasson (2004) measured and modeled estimates of fall water requirements for the seasonally flooded and permanently flooded wetlands at the Lower Klamath NWR, located in the Lost River HUC8 sub-basin. They found that 60 percent of the total volume of inflow to the wetlands goes to saturate the underlying soils, adding to the water needs of seasonally flooded wetlands. Once the soils are saturated, little loss to infiltration or groundwater seepage in the wetlands would occur. Annual water requirements for both types of wetlands were comparable. Wetlands with 50 percent emergent vegetation and 50 percent open water had an estimated annual ET of 3.05 feet per year over the period 1999–2001. Using the current estimated wetland area of 341,154 acres from the National Wetlands Inventory (USFWS, 2014) for emergent wetlands in the Klamath River Basin along with the above ET rate, the estimated mean annual wetlands ET would be 1,040,910 AFY.

Stannard et al. (2013) sought to improve understanding of ET losses from wetlands by taking ET measurements using the eddy-covariance method from May 2008 through September 2010 at two sites near Upper Klamath Lake. As noted above, they estimated the area of wetlands near Upper Klamath Lake as approximately 70 square kilometers (17,300 acres). From their ET measurements, they found that during the average 190-day alfalfa-growing season, wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. In this study, Stannard et al. estimated a wetland ET rate of approximately 3.08 feet per year. If we extrapolate their computed rate for wetland ET to include the area identified in the National Wetlands Inventory (341,154 acres), their resulting estimate of mean annual wetland ET is 1,049,862 AFY.

[25] Note that the mean ET rate was computed as the mean rate across HUC8 sub-basins, while average annual current wetland ET was calculated as the ET rate multiplied by area, each unique by HUC8 sub-basin, then summed over the entire basin. The average annual current wetland ET is not mathematically equivalent to the mean ET rate multiplied by the basin's 341,154 acres of emergent wetlands. Conversely, the average annual current wetland ET computed using methods by Mayer and Thomasson (2004) and Stannard et al. (2013) was computed as the ET rate multiplied by the total basin area.

4.2.2.2 Lake and Reservoir Evaporation

The reservoirs evaluated by the study are listed in Table 4-14 along with their capacity and ownership information. Historical evaporation rates (in inches per year) and volumes (in AFY) for these reservoirs have been estimated using an energy balance model, as described below. The historical rates provide the baseline against which future estimates are compared in later sections of this chapter.

Table 4-14. Klamath River Basin primary reservoirs

Reservoir	Storage Capacity (AF)	Maximum Surface Area (acres)	Owner
Clair Engle Lake	2,448,000	17,851	Reclamation
Upper Klamath Lake	629,780	90,000	Reclamation
Clear Lake	513,330	25,760	Reclamation
Gerber Reservoir	104,460	4,000	Reclamation
Tule Lake	60,592	13,074	Reclamation
COPCO 1 Reservoir	46,867	1,000	PacifiCorp
Iron Gate Reservoir	58,794	944	PacifiCorp
John C. Boyle Reservoir	3,495	420	PacifiCorp

Source: PacifiCorp (2004c)

The estimated evaporation rates for the Reclamation reservoirs in the basin were calculated using the complementary relationship lake evaporation (CRLE) model (Morton et al., 1985). CRLE is an open water evaporation model that accounts for water temperature, albedo, emissivity, and heat storage effects to estimates of monthly evaporation. Reclamation collaborated with the DRI (Reno, Nevada) in the development and application of the model for this study.

The collaborative reservoir evaporation modeling effort with DRI was initiated as part of the WWCRA. Under the WWCRA work, Upper Klamath Lake evaporation was modeled along with 11 other reservoirs in the western U.S.

The WWCRA Water Demands Report (Reclamation, 2015) provides a detailed description of the CRLE model and its application for Upper Klamath Lake. The model parameters for Upper Klamath Lake developed under the WWCRA were directly applied for simulation of open water evaporation in Upper Klamath Lake in this study. The other reservoirs listed in Table 4-14 were also modeled using the same approach.

The CRLE model calculates estimated evaporation for historical average reservoir conditions. Average monthly historical reservoir conditions (storage volume and surface area) were calculated using historical data and assumed constant for the analysis period (1950–1999). The same air temperature-based relationship used for estimating solar radiation for Upper Klamath Lake, based on Klamath Falls

Agrimet weather station data, was applied for modeling evaporation at the other reservoirs. Relationships for estimation of dewpoint depression (humidity) were developed based on historical data from the weather stations, discussed above in Section 4.2.1.1, Agricultural Irrigation, and as shown in Figure 4-2.

Table 4-15 includes a summary of the CRLE model results for the historical baseline period (1950–1999), including average annual evaporation rates and net evaporation (evaporation minus precipitation) rates for each reservoir. Table 4-15 also includes evaporation and net evaporation volume estimates based on the model results and historical average reservoir conditions. Note that historical average reservoir conditions differ from the maximum conditions reported in Table 4-14.

Table 4-15. Klamath River Basin reservoirs evaporation model results summary for 1950 to 1999 historical baseline period

Reservoir	Evaporation (inches/year)	Evaporation (AFY)[26]	Net Evaporation (inches/year)	Net Evaporation (AFY)[11]
Clair Engle Lake	45.0	49,152	-26.0	-28,412
Upper Klamath Lake	44.0	263,483	21.1	125,977
Clear Lake	45.6	81,711	32.0	57,300
Gerber Reservoir	44.4	8,947	24.1	4,862
Tule Lake	45.2	23,723	33.3	17,484
COPCO 1 Reservoir	43.9	3,427	20.8	1,626
Iron Gate Reservoir	44.8	3,446	27.2	2,089
J.C. Boyle Reservoir	44.2	729	22.5	371

Stannard et al. (2013) conducted an open water and wetland evaporation study for Upper Klamath Lake, Oregon. Bowen ratio energy balance was utilized to estimate open water evaporation during the summer and fall of 2008 and the growing seasons of 2009 and 2010. To evaluate the skill of CRLE application in the Klamath River Basin, the CRLE model was forced with measured solar radiation, air temperature, and dewpoint temperature obtained from the Klamath Falls Agrimet station for the 2008–2010 study period of Stannard et al. (2013). Results of the seasonal comparison are favorable, with daily average evaporation rates for this study of 0.20 inches per day compared to 0.21 inches per day by Stannard et al. (2013).

[26] Reservoir evaporation and net evaporation volumes were computed using mean monthly surface area over the simulation period.[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

Deleted: ¶

4.2.2.3 Operational Inefficiencies

Operational inefficiencies such as canal seepage and on-farm losses associated with irrigation methods are not explicitly quantified in the Klamath River Basin Study. The largest irrigated region in the watershed is Reclamation's Klamath Project. Within the Project area, on-farm runoff and canal spills are captured in drains and reused such that the overall efficiency of the Project is considered to be relatively high. This is based on water budgets developed as part of previous studies (Davids, 1998; Freeman and Burt, undated; Reclamation, 2007b). For other irrigated regions, such as the Shasta and Scott Valleys, this study assumes that non-beneficial consumptive use of conveyance and on-farm losses is not a significant portion of the overall losses in the watershed. The USGS Water Use Program estimates for agricultural irrigation use include crop demands, conveyance losses, and on-farm losses.

4.2.2.4 Phreatophyte Vegetation

Phreatophytes are defined as deep-rooted plants that obtain water from the water table or in the vadose zone just above the water table. Phreatophyte losses are included in the water budget through the natural flow computations (refer to Chapter 3) and therefore are not shown separately as losses. Needs of other vegetation for water are also included in the water budget. For example, BLM and USFS conservation initiatives associated with the 1994 Northwest Forest Plan preserve old growth vegetation and riparian buffers throughout the Southern Oregon / Northern California Coast Evolutionary Significant Unit and range of the Northern Spotted Owl (BLM and USFS, 2005).

4.2.3 Non-Consumptive Uses

Non-consumptive uses are those which do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.), water needs to support fish and wildlife, and hydropower production, among others. In one sense, these uses may be considered demands in that certain water levels or flows are required to support them. However, because these uses do not result in a loss of water in a planning context, the Klamath River Basin Study addresses them in terms of measures of system reliability. The measures are used to evaluate how well the available water supply is able to meet various needs in the watershed.

> **Non-Consumptive Uses**
>
> Non-consumptive uses include recreation, environmental resources, hydropower, and aquaculture. Because non-consumptive uses do not result in a reduction of available water supply, they are addressed in Chapter 5, System Reliability as measures for evaluating the impacts of climate change and implementation of adaptation strategies.

This section briefly describes the identified non-consumptive uses in the Klamath River Basin. However, details of water requirements and/or needs to sustain these uses are further quantified in Chapter 5, System Risk and Reliability Analysis.

4.2.3.1 Recreation

The expansive rural landscape of the Klamath River Basin offers a myriad of outdoor recreational opportunities, many of which are either directly or indirectly associated with the basin's water resources. Rivers, streams, and lakes are common throughout the basin's mountainous landscape, and reservoirs and wetlands exist in the valleys and high plateau areas of the central and eastern portions of the basin. The basin's rivers, streams, lakes, reservoirs, and wetlands provide a variety of recreational opportunities including camping, sightseeing, hunting, fishing, boating, hiking, and wildlife viewing.

There are five national forests within the basin (Klamath, Fremont, Winema, Six Rivers, and Modoc), a joint national and State park (Redwood), a national park (Crater Lake), two national monuments (Lava Beds and Cascade-Siskiyou) and five national wildlife refuges that make up the Klamath Basin NWR Complex (Klamath Marsh, Tule Lake, Clear Lake, Upper Klamath, and Lower Klamath). Recreation opportunities in these forests, parks, and refuges include camping, hiking, snowmobiling, sightseeing, wildlife viewing, hunting, and fishing.

Large sections of the Klamath River and its tributaries are designated as national wild and scenic rivers (WSR) under the Wild and Scenic Rivers Act, including segments of the Klamath, Scott, and Salmon Rivers and Wooley Creek totaling 297 miles. Extensive public and private recreational opportunities exist along the Klamath River and its tributaries.

The Klamath River Basin Study focuses on flow-related recreational uses, as they are more directly associated with water supply than other recreational demands such as camping and sightseeing, for example. The recreational uses considered in this study are fishing and boating in the Klamath and Trinity Rivers. Chapter 5, System Reliability quantifies optimal flow ranges for these activities, as reported by the Klamath Facilities Removal EIS/EIR (Interior and CDFG, 2012).

The modeling framework of the Klamath River Basin Study does not allow for evaluation of impacts of climate change on natural unmanaged lakes within the watershed; however, evaluation of reservoir levels is part of the system reliability analysis in Chapter 5.

4.2.3.2 Environmental Resources

Numerous fish species use the Klamath Basin during all or some portion of their lives. Native species include salmonids, lamprey, sturgeon, suckers, minnows, and sculpin. Many other species are present in the Klamath River estuary. Salmonids in the Klamath River include fall and spring Chinook salmon; coho salmon; fall-, winter-, and summer-run steelhead; and coastal cutthroat trout. The salmonids share many similar life-history traits, but the timing of their upstream

migrations, habitat preferences, and distributions differ (Interior and CDFG, 2012). A number of non-native species have also been introduced into the watershed including yellow perch, largemouth bass, spotted bass, sunfish, and catfish. These species all have unique needs for Klamath River water which must be considered in conjunction with management practices for human uses.

Water Quality

Water quality in the Klamath River Basin is affected by both natural and human influences. The volcanic terrain supports soils that are naturally high in phosphorus. Human influences including development, wetland draining, agriculture, ranching, logging, and water management have altered streamflows and water temperatures and increased nutrient and sediment loading in the river system. In addition, mining activities, dam construction, and management for hydropower in the Lower Klamath Basin have further affected river conditions (Interior and CDFG, 2012). As a result of natural and human activities, water quality standards in the Upper Klamath Basin have not been met for many years (Stillwater Sciences, 2013). Table 4-16 summarizes the water quality impaired water bodies in the Klamath River Basin as identified by the Klamath Facilities Removal EIS/EIR (Table 3.2-8 in Interior and CDFG, 2012). The identified water quality impairments impact the beneficial uses of the Klamath River designated by the Klamath Facilities Removal EIS/EIR, which are categorized as Aesthetic and Cultural, Agricultural Water Supply, Commercial, Fish and Wildlife, Potable Water Supply, Industrial Water Supply, and Navigation.[27] For example, known and/or perceived concerns over health risks associated with seasonal algal toxins have resulted in the alteration of traditional cultural tribal practices such as gathering and preparation of basket materials and plants, fishing, ceremonial bathing, and ingestion of river water.

[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

Table 4-16. Water quality impaired water bodies within the area of analysis[1]

Water Body Name	Water Temperature	Sedimentation	pH	Organic Enrichment/Low Dissolved Oxygen	Nutrients	Ammonia	Chlorophyll-a	Microcystin
Oregon[2]								
Sprague River and tributaries	X^{S}		X^{S}	X^{S}				
Williamson River and tributaries	X							
Upper Klamath Lake and Agency Lake			X	X			X	
Upper Klamath River (Keno Dam to Link River Dam, including Keno Impoundment/Lake Ewauna)			X^{S}	$X^{SP,S,F,W\ (3)}$		$X^{SP,S,F,W}$	X^{S}	
Upper Klamath River Oregon-California state line to Keno Dam (including J.C. Boyle Reservoir) (4)	$X^{SP,S,F,S\ (5)}$			$X^{SP,S,F,W\ (3)}$				
California								
Lower Lost River (Tule Lake, Lower Klamath Lake National Wildlife Refuge, and Mt. Dome)			X		X			
Middle Klamath River Oregon-California state line to Iron Gate Dam (including COPCO Lake Reservoir [1 and 2] and Iron Gate Reservoir)	X			X				X
Middle Klamath River Iron Gate Dam to Scott River Reach 6	X			X	X			X
Shasta River	X			X				
Scott River	X	X						
Salmon River	X							
Middle and Lower Klamath River Scott River to Trinity River Reach 7	X			X	X			X
Lower Klamath River-Trinity River to Mouth	X	X		X	X			

Source: Table 3.2-8 in Interior and CDFG, 2012

Notes:

1 While there are additional water quality impaired waterbodies in the area of analysis, the waterbodies listed in this table are the ones that are directly relevant to the water quality analysis for this Klamath Facilities Removal EIS/EIR.

2 Oregon lists specific reaches of the Klamath River by river mile and includes specific seasons, in some cases (Kirk et al., 2010).

3 Listed for dissolved oxygen only (non-spawning) (Kirk et al., 2010).

4 Oregon defines particular river miles for their listings.

5 Non-spawning (Kirk et al., 2010).

6 Selected minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include Beaver Creek, Cow Creek, Deer Creek, Hungry Creek, and West Fork Beaver Creek (USEPA, 2010a).

7 Minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include China Creek, Fort Goff Creek, Grider Creek, Portuguese Creek, Thompson Creek, and Walker Creek (USEPA, 2010a).

Key:

Sp = Listed for spring season

S = Listed for summer season

F = Listed for fall season

W = Listed for winter season

Effects on regional water quality have resulted in multiple federal, state, and tribal programs and planning documents to regulate and protect water quality in the area of the Klamath River Basin. For example, the states of Oregon and California have established and obtained EPA approval of water quality standards (referred to as "water quality objectives" in California) for waters in the Klamath River Basin, including designated beneficial uses (PacifiCorp, 2004b; Interior and CDFG, 2012). Also, several of the Klamath River Basin native tribes have adopted their own water quality objectives for portions of the Klamath and Trinity Rivers. Water quality objectives adopted by the Hoopa Valley Tribe establish water quality objectives for those portions of the Trinity and Klamath Rivers under the jurisdiction of the tribe. The Yurok and Karuk Tribes have also adopted water quality objectives, as has the Resighini Rancheria; however, the associated water quality plans have not yet been approved by USEPA (NCRWQCB, 2010b).

For water bodies included on the Clean Water Act Section 303(d) list of impaired water bodies, the state with jurisdiction over the water body must develop TMDLs to protect and restore beneficial uses of water. TMDLs set limits on the amount of pollutants that can be added to a water body while still protecting identified beneficial uses. TMDLs have been established for various parts of the Klamath River Basin since about 2001. The status and pollutants regulated under Klamath River Basin TMDLs are summarized in Table 3.2-9 of the Klamath Facilities Removal Final EIS/EIR (Interior and CDFG, 2012).

Water levels and flow rates are inherently related to water quality in the Klamath River Basin. The need for improved water quality by environmental resources may be considered a demand, in one sense, because threshold flows are needed to sustain a healthy river system. However, because these needs are non-consumptive, the Klamath River Basin Study incorporates water quality criteria and associated TMDLs in the analysis of system reliability. Specifically, environmental health of the watershed is assessed through analysis of water temperature as a surrogate for overall watershed ecological health. Water quality criteria and TMDLs for stream temperature are incorporated as measures for evaluation of system reliability in Chapter 5.

Instream Flow Targets

Instream flow targets have been established for parts of the Klamath River Basin both through state codes, state and federal regulatory requirements, and cooperative agreements such as Reclamation's 2013 Biological Assessment for Proposed Klamath Project Operations and the associated 2013 non-jeopardy [28] Biological Opinion issued by the NMFS and USFWS. Instream flow targets are one means of working toward the maintenance and even recovery of threatened and endangered species in the basin. However, recommended instream flows are highly uncertain due to limited data availability and our limited understanding of

[28] An ESA Section 7 non-jeopardy Biological Opinion is one where USFWS or NMRS determines that a federal action is not likely to jeopardize the existence of a listed species or result in the destruction or adverse modification of critical habitat.

all of the direct and indirect effects of the environment on the species it supports. As we learn more about species recovery in responses to instream flow actions, these recommendations are likely to evolve through time.

Instream flow recommendations exist for reaches of the Klamath River (Reclamation, 2012d; NMFS and USFWS, 2013; Interior and CDFG, 2012; Hardy et al., 2006) as well as the tributaries of the Shasta River (McBain and Trush, 2014) and Trinity River (Interior, 2000). In addition, the federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. Interior supports Winters Doctrine rights which entitle tribes in the Klamath River Basin to sufficient water to support fishing and harvesting and cultural practices. Also, recognition of tribal reserved fishing rights is consistent with the federal precedent set in United States v. Adair (Interior and CDFG, 2012). Although the Klamath River Basin tribes have reserved rights to support their livelihoods, for the most part instream flow needs to support those activities have not been quantified, with the exception of the Klamath Tribes as part of Oregon's Klamath Basin adjudication process.

Similar to other non-consumptive water uses, recommended instream flow targets may be considered a demand in that certain flows are required to sustain fish species and support other uses. However, since these uses do not result in a reduction of water supply, they are incorporated in the analysis of system reliability in Chapter 5. Namely, instream flow targets may be used as measures in the evaluation of impacts of climate change on the watershed with and without implemented adaptation strategies. Details of recommended instream flow targets are included in Chapter 5.

Wildlife Refuge Water Targets

Klamath Basin National Wildlife Refuges is a complex of six refuges: Lower Klamath, Tule Lake, and Clear Lake in northern California and Bear Valley, Upper Klamath, and Klamath Forest Refuges in southern Oregon. All of the complex refuges are adjacent to or within Reclamation's Klamath Project with the exception of Bear Valley, which was established in 1978 and consists of old growth pine forest to protect a major night roost site for wintering bald eagles in Southern Oregon. The USFWS manages the refuges under the Migratory Bird Treaty Act (codified as 16 U.S.C. §§ 703-712), National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. §§ 668dd-668ee), National Wildlife Refuge System Improvement Act (Pub. L. 105-57, 111 Stat. 1252-1260), and other laws pertaining to the NWR System (Reclamation, 2012d). They were established by various executive orders starting in 1908, and support many fish and wildlife species and provide suitable habitat and resources for migratory birds of the Pacific Flyway. Each year these refuges serve as an annual stopover for approximately three-quarters of the flyway waterfowl with peak concentrations of over one million birds. Reclamation manages leases on refuge lands for agricultural purposes through a cooperative agreement with the USFWS (Reclamation, 2012d).

The refuges (with the exception of Bear Valley and Clear Lake) have federally-reserved water right claims for the water necessary to satisfy the refuges' primary purposes subject to more senior water rights in the basin, including the Klamath Tribes and Reclamation's Klamath Project. The 2013 BA for Klamath Project operations outlines the availability of water to the Lower Klamath and Tule Lake NWRs (Reclamation, 2012d). In addition, Risley and Gannett (2006) estimated water needs of the Lower Klamath and Tule Lake NWRs using evapotranspiration estimates, with different rates for each of four land-use categories. With the exception of open water evaporation and wetland ET, water used by refuges is generally non-consumptive. Recommended targets, like those summarized by the above sources, are provided in Chapter 5, System Reliability and incorporated as measures for evaluation of system reliability.

4.2.3.3 Hydropower

The Klamath River Basin has nine major hydropower generating facilities, seven in the Upper Klamath Basin and two in the Trinity River sub-basin. Other small hydropower generating facilities in the basin include the C Drop Plant on Reclamation's Klamath Project and two small hydropower facilities in Siskiyou County. The seven major hydropower plants in the Upper Klamath Basin are owned and operated by PacifiCorp of Portland, Oregon. The PacifiCorp facilities are regulated by the Federal Energy Regulatory Commission (FERC) as Project No. 2082 and are operating under annual licenses since the expiration of the original license in March 2006. Future operations are dependent on the resolution of the relicensing proceedings for these facilities, which may be addressed through either issuance of a new project license by FERC or the passage of federal legislation enacting the Klamath Hydroelectric Settlement Agreement (KHSA) and related Klamath settlements, which provide for the potential removal of these facilities.

Since 1992, operations of PacifiCorp's facilities have been adjusted to protect ESA-listed threatened species. These adjustments were made to address then-current minimum levels in Upper Klamath Lake and minimum instream flows in the Link River and in the Klamath River below Iron Gate dam described in biological opinions for Reclamation's Klamath Project (PacifiCorp, 2004b). The current river flow and Upper Klamath Lake level requirements are described in the 2013 Joint Biological Opinion for Klamath Project Operations by the USFWS and NMFS (NMFS and USFWS, 2013). If PacifiCorp's hydroelectric dams are removed as part of the KBRA/KHSA, the hydroelectric water rights at all of PacifiCorp's Klamath facilities (except Fall Creek) in Oregon will be dedicated or assigned to instream water rights and administered by the ODFW, while those in California will be abandoned, according to Section 7.6.5 of the KHSA.

The other two major hydropower generating facilities are located in the Trinity River sub-basin. The Lewiston powerplant provides power to the adjacent Trinity River Fish Hatchery and additional energy is sold. Trinity Power plant is a peaking plant associated with the Trinity River Diversion for Reclamation's Central Valley Project. Flow rates and associated power production at both

facilities are subject to the Trinity River Restoration Program Record of Decision (Interior, 2000).

The Klamath River Basin Study provides the basis for evaluations of changes in future hydrologic conditions and resulting changes in power generation capacity and timing. The analysis of system reliability (refer to Chapter 5) allows for quantification of projected turbine releases and hydropower production as a result of climate change and implemented adaptation strategies. This study does not evaluate projected changes in the demand for hydropower in a changing climate. Water rights and instream flow requirements associated with hydropower production are utilized in the system reliability analysis as measures for evaluation of changes in power production associated with various managed flow conditions in a changing climate.

4.2.3.4 Aquaculture

Another non-consumptive use of water within the Klamath River Basin includes aquaculture, which is defined as the rearing of aquatic animals. This use is quantified by the USGS Water Use Program; however, the percentage of total basin water use is only 3 percent. Due to the small percentage of overall water use, the fact that this use is largely non-consumptive, and the lack of information as to the impacts of climate change on aquaculture, this use is not further considered in the Klamath River Basin Study.

4.3 Effects of Climate Variability and Change on Demand

4.3.1 Climate Change Scenarios

The Klamath River Basin Study primarily utilizes climate change scenarios that are derived using an ensemble informed hybrid delta (HDe) method approach (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d). The scenarios are derived from both CMIP3 and CMIP5 bias corrected and spatially downscaled (BCSD) GCM climate projections, as these are considered equally likely potential climate futures at this time. The approach allows a high number of CMIP3 and CMIP5 climate projections to be distilled into a small number of representative climate change scenarios. The same scenarios used for evaluation of future water supply are used in this chapter's estimation of demands to meet consumptive uses, namely M&I and rural domestic as well as losses due to reservoir evaporation. Development of future agricultural scenarios involved using similar climate change scenarios, but with prior adjustments made to the underlying BCSD climate projections to account for biases in projected versus observed weather over irrigated areas (for more information, refer to WWCRA Demands Assessment, Reclamation, 2015).

Development of climate change scenarios is described in Section 3.5.1.2, Deriving Climate Change Scenarios from Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in

this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). Five scenario types are derived from the large number of CMIP3 and CMIP5 BCSD climate projections: warm-wet (WW), warm-dry (WD), central-tendency (CT), hot-wet (HW), and hot-dry (HD). Discussions of how the temperature and precipitation projections for the five HDe scenarios are used to estimate the various future demands are provided in the following sections.

4.3.2 Growth Scenarios

Future water demand with respect to consumptive uses and evaporation losses may have a number of driving forces aside from those directly related to climate, including demographics, land use, technological development, and socioeconomics. Because it is highly uncertain how these driving forces may unfold in the future, we employ a scenario-based approach to projected growth.

To evaluate the impacts of climate change on system performance of existing and anticipated water infrastructure and operations in the Klamath River Basin, a baseline condition is established. In typical long term planning studies, this baseline condition may be called the Future No Action alternative. A Future No Action alternative incorporates climate change scenarios and requires that assumptions be made regarding future growth in the watershed. The Future No Action alternative in the Klamath River Basin Study corresponds with one future growth scenario and ten climate change scenarios (five CMIP3-based scenarios and five CMIP5-based scenarios), each for the 2030s and 2070s, for a total of twenty future scenarios.

In general, the growth scenario encompasses projected population growth, where reported by the states and municipalities, and current agricultural practices. A brief description of the growth scenario is provided in this section. Assumptions regarding the future growth scenario are summarized below and in Table 4-17. Additional details regarding the growth scenario are provided in Section 4.3.3 which quantify the impacts of climate change on water demands.

As shown in Table 4-17, this study assumes that cropping patterns and number of irrigated acres are static in quantifying future agricultural irrigation demands. Altered cropping patterns may be considered in this study as implemented adaptation strategies in the analysis of system reliability. For M&I and rural domestic uses, a defined percentage of the water use is landscape irrigation and this is also considered static. Population estimates that define the total M&I and rural domestic future water usage are based on two primary sources. If population projections are provided by individual municipal water plans, those projections are incorporated into the demand scenario. For regions where municipal water plans may not exist, and for rural domestic water use, historical population trends are extrapolated into the future and incorporated in the demand scenario. For losses due to reservoir or lake evaporation, it is assumed that historical average reservoir levels exist in the future. Alternative future reservoir levels are considered as implemented adaptation strategies in the analysis of system reliability. Finally, for future wetland ET estimates, it is assumed that the current

number of wetland acres (based on the current National Wetland Inventory) is static.

Table 4-17. Summary of assumptions for Klamath River Basin Study future growth scenario

Consumptive Use or Loss	Element	Assumptions for Future Scenarios
Agricultural irrigation		
	Cropping patterns	Static, based on historical
	Irrigated acres	Static, based on historical
M&I and rural domestic	Landscape irrigation = 40 percent of total use	Static, based on historical
	Population growth	Based on water plans or extrapolations of historical trends (if projections not available)
Lake and reservoir evaporation	Average lake and reservoir levels	Static, based on historical
Wetlands ET	Wetland acres	Static, based on historical

4.3.3 Projected Future Water Demands

Numerous factors were considered in the estimation of the basin’s future water demands. The primary factors include population growth, agricultural practices, and climate change. Population growth, agricultural practices, and other socioeconomic conditions are incorporated in the demand scenario described above. Projections of climate change are incorporated separately, such that there are five HDe climate scenarios for each of the CMIP3- and CMIP5-based projections and for each future time horizon (2030s and 2070s). Each of these climate change scenarios is paired with the single demand scenario considered in this study.

As discussed previously, rigorous quantitative analyses were performed to estimate the demands to meet predominant consumptive uses in the watershed: agricultural irrigation, M&I, rural domestic, wetlands, and losses due to reservoir evaporation. The implications of climate change on non-consumptive uses are evaluated as part of Chapter 5, System Reliability Analysis.

Table 4-18 summarizes the projected changes in basin-wide consumptive use (both human influenced and natural) for the predominant use categories: agricultural irrigation, M&I, rural domestic, and losses due to reservoir evaporation and wetland ET. Projected changes are presented for all five HDe climate change scenarios for each of the CMIP3- and CMIP5-based projections, as well as for two future time horizons, the 2030s and 2070s.

Table 4-18. Summary of basin-wide projected changes in consumptive water use and losses

Scenario	Period	BCSD Projection	Total (AFY)	Total Percent Change
Historical	Historical	-	2,039,430	-
Warm Dry	2030	CMIP-3	2,233,781	10%
Warm Dry	2030	CMIP-5	2,277,042	12%
Warm Wet	2030	CMIP-3	2,190,454	7%
Warm Wet	2030	CMIP-5	2,225,238	9%
Hot Dry	2030	CMIP-3	2,387,983	17%
Hot Dry	2030	CMIP-5	2,405,865	18%
Hot Wet	2030	CMIP-3	2,313,274	13%
Hot Wet	2030	CMIP-5	2,349,212	15%
Central Tendency	2030	CMIP-3	2,284,936	12%
Central Tendency	2030	CMIP-5	2,304,374	13%
Warm Dry	2070	CMIP-3	2,380,969	17%
Warm Dry	2070	CMIP-5	2,324,159	14%
Warm Wet	2070	CMIP-3	2,308,778	13%
Warm Wet	2070	CMIP-5	2,266,970	11%
Hot Dry	2070	CMIP-3	2,528,603	24%
Hot Dry	2070	CMIP-5	2,568,869	26%
Hot Wet	2070	CMIP-3	2,428,364	19%
Hot Wet	2070	CMIP-5	2,501,320	23%
Central Tendency	2070	CMIP-3	2,393,777	17%
Central Tendency	2070	CMIP-5	2,406,350	18%

Similarly, for all future climate scenarios Figure 4-5 summarizes projected changes for each type of consumptive use or loss considered in the Klamath River Basin Study for the 2030s and 2070s.

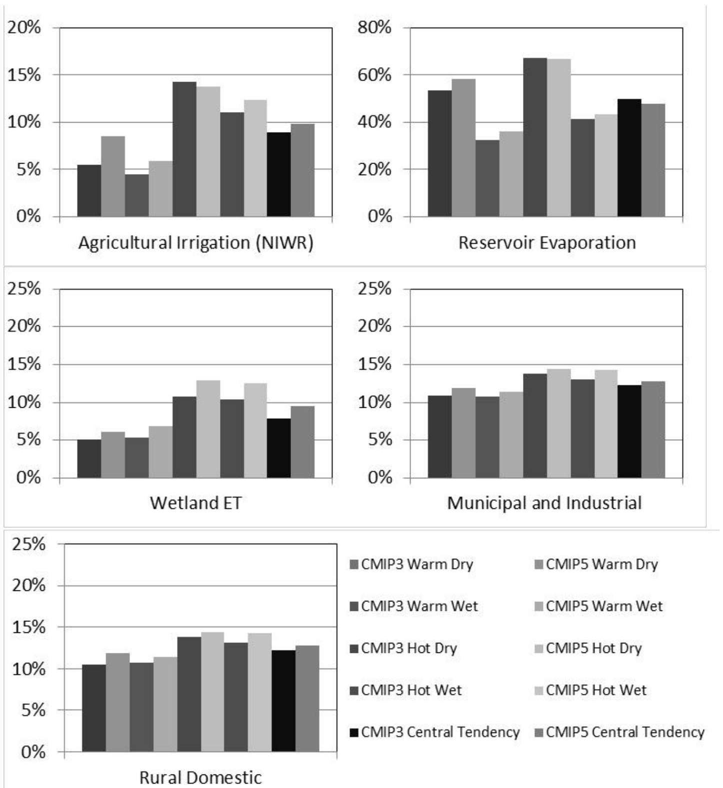

Figure 4-5. Summary of basin-wide projected changes in consumptive water use and losses for the 2030s by use type

4.3.3.1 Human Influenced Consumptive Uses

Projected consumptive uses to meet future demands are summarized in this section, incorporating projected HDe climate scenarios for two future time horizons, the 2030s and the 2070s, and a single future growth scenario. Descriptions of the approaches used to incorporate climate change scenarios and growth scenarios are provided in the respective subsections below on various consumptive uses and losses.

Agricultural Irrigation

To evaluate the impacts of climate change on agricultural irrigation demands, the ET Demands model described in Section 4.2, Current Demand was implemented using the approach described in Reclamation (2015). Any differences in the approach details are discussed below.

For example, the Klamath River Basin Study utilizes two future time periods for analysis of climate change impacts (2030s and 2070s), compared with three future time periods (2020s, 2050s, 2080s) used in the WWCRA. Also, there are slight differences in the projection ensemble selection process for development of HDe scenarios. This study utilizes a subset of 10 climate projections to inform each of the five climate scenarios, while the WWCRA utilizes the full set of climate projections. Further discussion of the approach for climate change scenario development for this study is provided in Chapter 3. Another difference in approach for assessing agricultural irrigation demands is the use of both CMIP3 and CMIP5 projections in this study; the WWCRA uses solely CMIP3 projections. At the time the WWCRA work began, CMIP5 projections were not readily available.

As mentioned above, a single growth scenario was used in conjunction with multiple future climate scenarios to encompass a range of potential future consumptive water demands. Collectively these scenarios comprise the Future No Action scenario. This alternative generally includes historical cropping patterns and irrigated acreage. Additional approach details for assessment of future agricultural irrigation demands are provided in this section. In the discussion of Current Water Demands, the ET Demands model is described as using basal crop coefficient (K_{cb}) curves, which are developed as a function of GDD. For this study, the K_{cb} curves for annual crops are developed using baseline (historical) temperatures, while perennial K_{cb} curves are developed using future projected temperatures.

Changes in future farming practice of annual crops, such as potential earlier planting, development, and harvest, are uncertain under warming climatic conditions. These potential changes will depend on future crop cultivars, water availability, and economics. For these reasons, static phenology K_{cb} curves were simulated for future periods where historical baseline temperatures were used for simulating planting, crop development, and harvest dates using the GDD approach previously described. In effect, all scenarios and time periods have identical seasonal K_{cb} curve shapes for each annual crop, and only exhibit differences in daily ET_c magnitudes due to daily ET_o and precipitation differences. A detailed discussion on this static phenology approach is included in Reclamation (2015).

The future irrigation demands results cover mean annual precipitation, temperature, reference evapotranspiration (ET_o), crop evapotranspiration (ET_c), and net irrigation water requirement (NIWR, both depth and volume). Mean monthly values of perennial crop ET_c for future time periods and scenarios are also presented to highlight potential changes in seasonal ET_c.

The future ET_o, ET_c and NIWR subbasin and basin total estimates were calculated using the same methods as the historical baseline values. Specifically, the NIWR and ET_c rates for each crop within a given HUC8 subbasin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 subbasin,

and all crop values are summed to calculate weighted average HUC8 subbasin NIWR and ET_c rates. ET_o, ET_c and NIWR estimates for the entire basin were calculated using the ratios of subbasin to basin irrigated acres.

The results are summarized in a series of figures and tables (similar in format to the WWCRA [Reclamation, 2015]), with appended detailed results and additional figures. The figures below show projected changes in temperature, precipitation, ET_o, ET_c, and NIWR for the CMIP5-based climate scenarios and both future time periods (2030s and 2070s). CMIP3-based figures are shown in Appendix C. Projected changes are presented as the difference from historical baseline averages for temperature, and percent change from baseline averages for all other variables. Projected absolute values of ET_o, ET_c, and NIWR for the different scenarios and time periods are also included in Appendix C.

Figure 4-6 illustrates the spatial distribution of projected precipitation percent change for the different scenarios and time periods. Depending on the scenario, basin average precipitation percent changes range from -7.4 percent to +20.8 percent for the 2070 time period (considering CMIP5-based scenarios), with the central tendency scenario showing a general increase throughout the basin.

Figure 4-7 shows the spatial distribution of projected mean temperature change for the different climate scenarios and time periods. Increased temperatures are shown for all scenarios and periods. with slightly larger projected mean temperature changes in the northeast portion of the basin for all scenarios. Depending on the scenario, basin average temperature changes range from 1.6 to 8.4 degrees F for the 2070s time period (considering CMIP5-based scenarios).

Figure 4-8 shows the spatial distribution of projected ET_o percent change for different climate scenarios and time periods, and Table 4-19 provides a comparison of projected changes in annual ET_o for the central tendency climate scenario. Similar to temperature, the projected percent change in ET_o is larger in the northeast portions of the basin.

Figure 4-9 illustrates the spatial distribution of projected ET_c percent change for different climate scenarios and future periods, and Table 4-20 provides a comparison of projected changes in annual ET_c for the central tendency climate scenario. Spatial differences in the distribution of projected percent change in ET_c are largely due to differences in crop type and historical baseline ET_c. The northeast portion of the basin is projected to experience the largest percent change increase for all projected time periods, largely due to the fact that the difference between the projected and historical baseline ET_c is fairly large relative to the baseline estimate of ET_c (see Figure 4-4). The predominant crops in the Upper Klamath Basin include alfalfa, pasture grass, other hay, and winter wheat. In the Lower Klamath Basin, where alfalfa, other hay, and spring wheat are the dominant crops, projected increases in ET_c are lower. The Lower Klamath HUC8 subbasin has a projected decrease in ET_c, despite projected climate warming in all

HUC8 subbasins. The increase may be due to projected changes in the harvesting of grass hay, which is projected to occur earlier in the year.

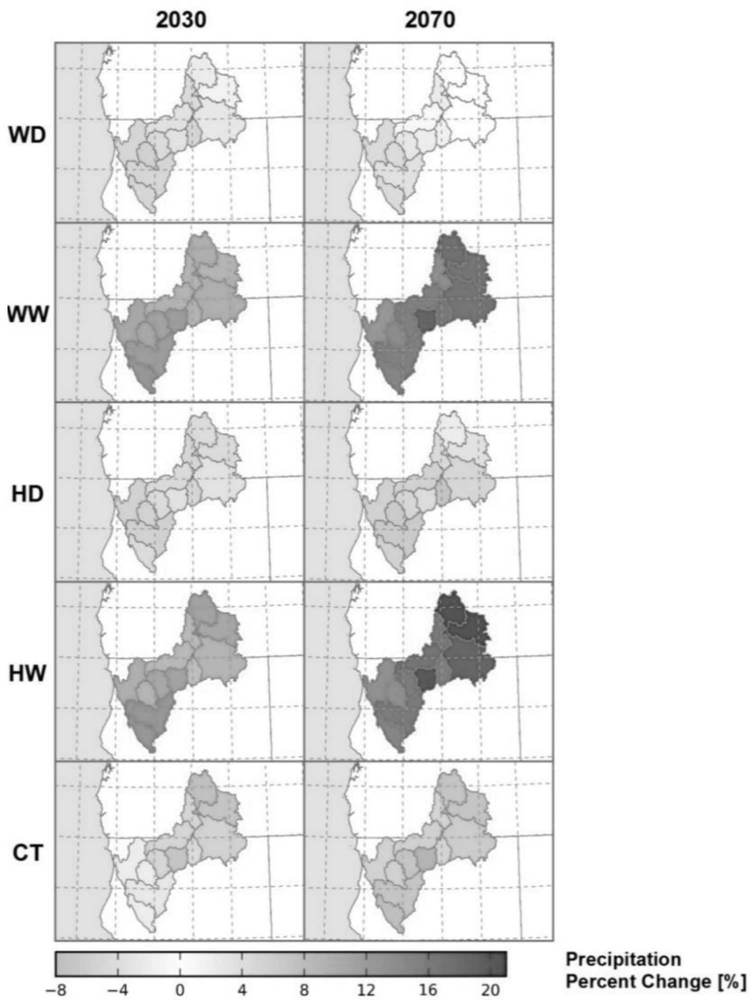

Figure 4-6. Klamath River Basin - Spatial distribution of projected precipitation change for different climate scenarios and time periods (CMIP5 climate scenarios)

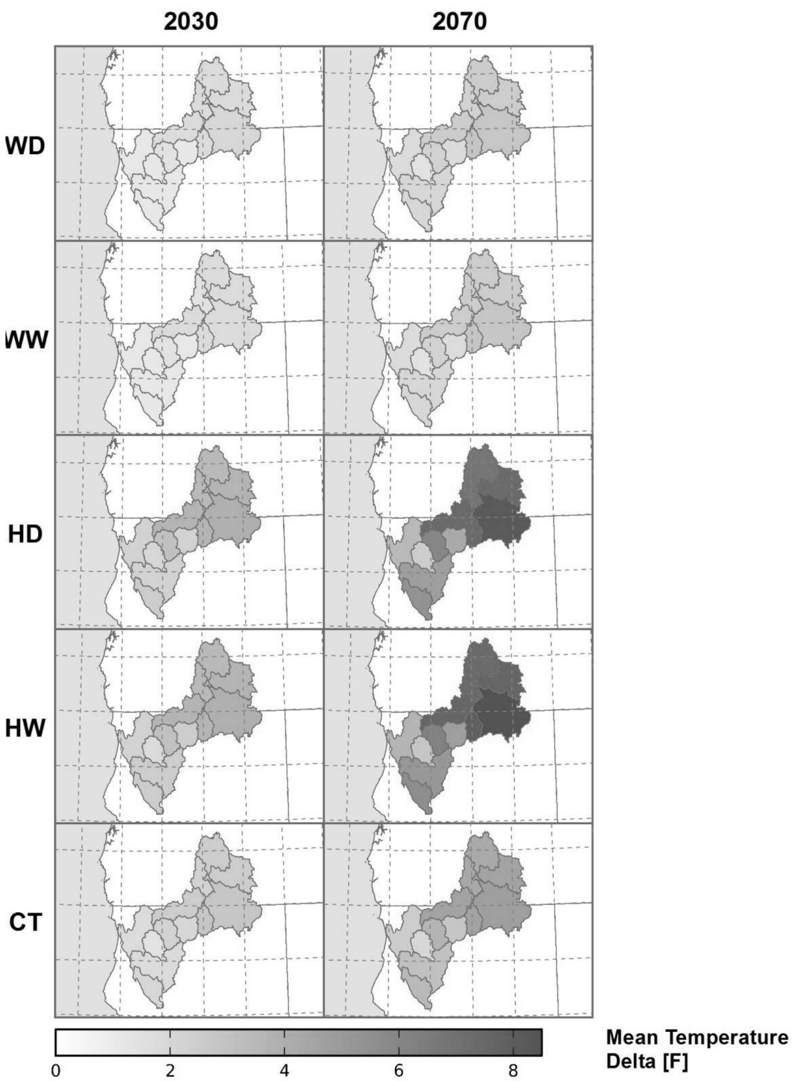

Figure 4-7. Klamath River Basin - Spatial distribution of projected temperature change for different climate scenarios and time periods (CMIP5 climate scenarios)

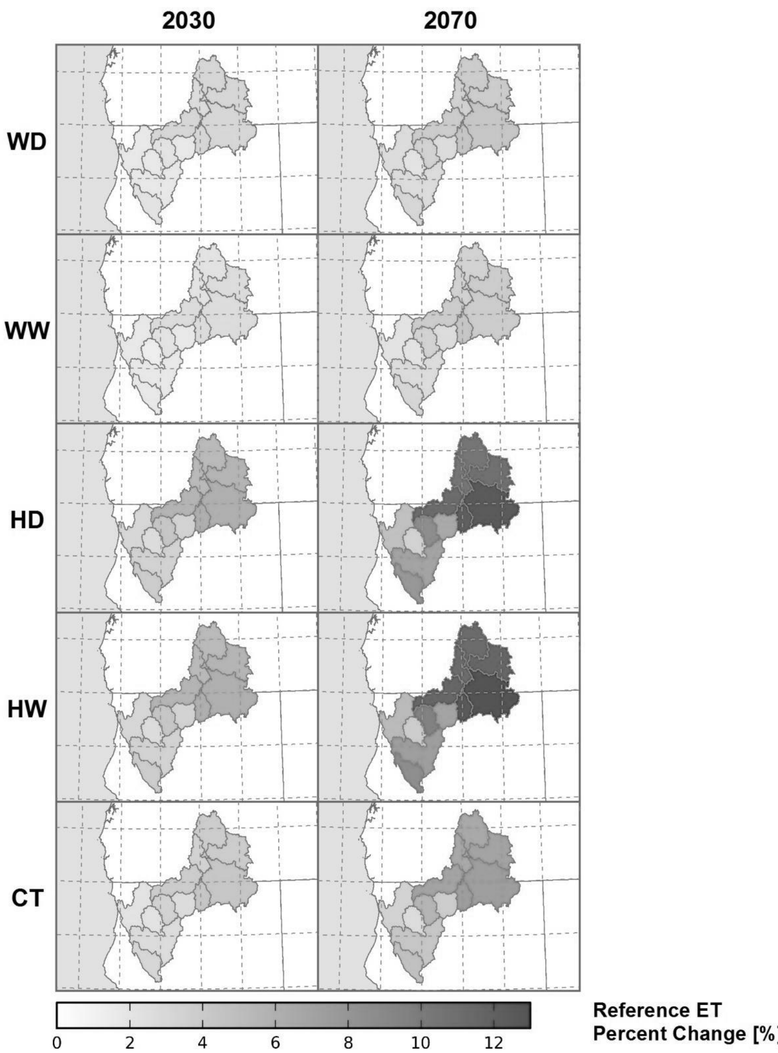

Figure 4-8. Klamath River Basin - Spatial distribution of projected reference evapotranspiration percent change for different climate scenarios and time periods (CMIP5 climate scenarios)

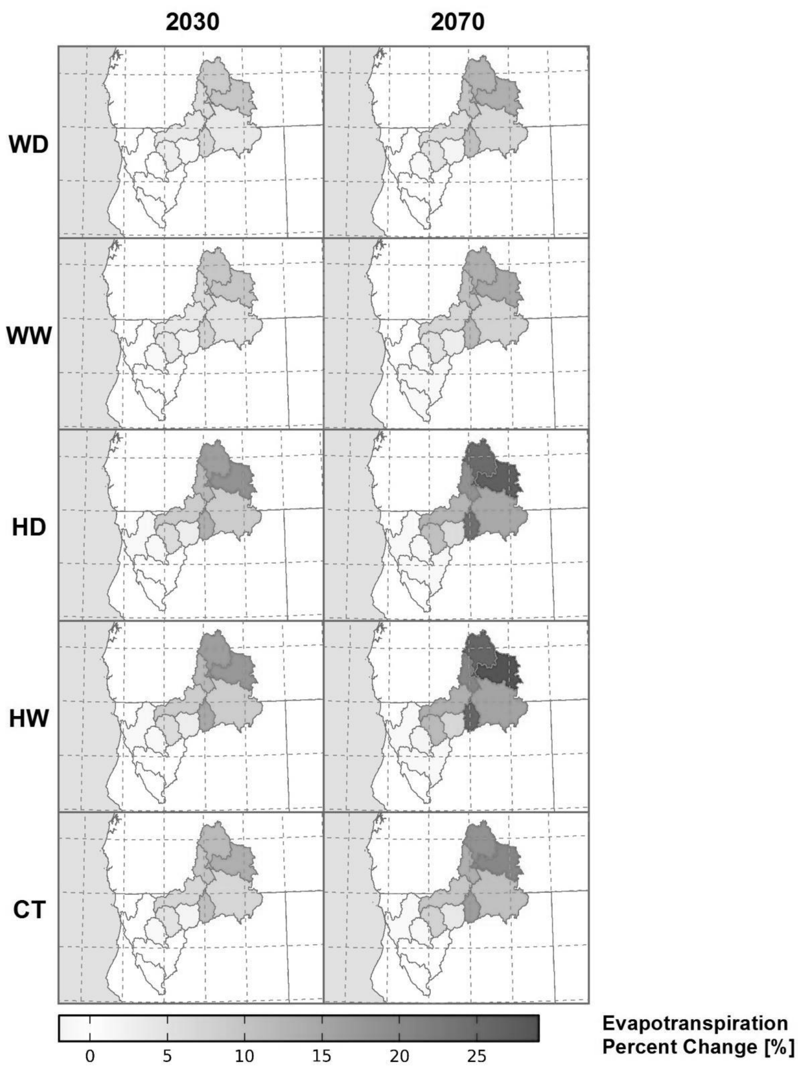

Figure 4-9. Klamath River Basin - Spatial distribution of projected crop evapotranspiration percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios).

Table 4-19. Comparison of projected changes in annual reference evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	3.3%	3.8%	5.9%	6.43%
HUC_18010202	Sprague	3.4%	4.0%	6.1%	6.7%
HUC_18010203	Upper Klamath Lake	3.2%	3.7%	5.7%	6.3%
HUC_18010204	Lost	3.6%	4.3%	6.7%	7.4%
HUC_18010205	Butte	3.7%	4.4%	6.6%	7.4%
HUC_18010206	Upper Klamath	3.5%	4.1%	6.1%	6.8%
HUC_18010207	Shasta	2.3%	2.7%	3.7%	4.2%
HUC_18010208	Scott	2.8%	3.4%	4.9%	5.5%
HUC_18010209	Lower Klamath	2.1%	2.4%	3.2%	3.4%
HUC_18010210	Salmon	2.0%	2.3%	2.8%	2.9%
HUC_18010211	Trinity	2.3%	2.7%	3.9%	4.3%
HUC_18010212	South Fork Trinity	2.5%	3.0%	4.4%	4.8%
Total Basin		3.4%	3.9%	6.0%	6.7%

Table 4-20. Comparison of projected changes in annual crop evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins.

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	10.0%	11.9%	16.6%	18.3%
HUC_18010202	Sprague	11.6%	13.8%	18.54%	20.4%
HUC_18010203	Upper Klamath Lake	6.9%	9.9%	12.8%	14.0%
HUC_18010204	Lost	5.7%	6.8%	9.6%	10.7%
HUC_18010205	Butte	9.1%	10.8%	14.8%	16.1%
HUC_18010206	Upper Klamath	5.4%	6.6%	8.9%	9.7%
HUC_18010207	Shasta	2.2%	2.6%	3.9%	4.4%
HUC_18010208	Scott	4.2%	4.9%	6.6%	7.6%
HUC_18010209	Lower Klamath	-0.7%	-0.9%	-1.1%	-1.2%
HUC_18010210	Salmon	1.0%	1.1%	1.3%	1.4%
HUC_18010211	Trinity	0.7%	0.8%	0.8%	0.9%
HUC_18010212	South Fork Trinity	0.8%	0.9%	0.7%	0.6%
Total Basin		6.1%	7.5%	10.3%	11.4%

All HUC8 subbasins show positive ET_c increases or no change, with the exception of the western-most HUC8 subbasin which exhibits slight decreases in ET_c under all scenarios by 2070 due to earlier harvest of grass hay.

The spatial distribution of projected NIWR percent change for different climate scenarios and time periods is shown in Figure 4-10, and a comparison of projected changes in annual NIWR for the central tendency climate scenario is provided in

Table 4-21. The NIWR incorporates growing season and non-growing season soil moisture gains and losses from precipitation, bare soil evaporation, and ET; therefore spatial variations in the distribution of NIWR percent change for different time periods and scenarios are a function of respective ET_c (Figure 4-9) and precipitation (Figure 4-6) distributions. For example, under the HD scenario precipitation is projected to decrease, whereas under the HW scenario precipitation is projected to increase. This results in NIWR increasing less in the HW scenario than in the HD scenario, though in both scenarios ETc changes are nearly identical.

Table 4-21. Comparison of projected changes in annual NIWR for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	16.1%	19.0%	26.1%	26.1%
HUC_18010202	Sprague	16.7%	18.4%	24.1%	25.0%
HUC_18010203	Upper Klamath Lake	10.5%	12.0%	17.2%	17.5%
HUC_18010204	Lost	8. 6%	9.4%	13.8%	14.2%
HUC_18010205	Butte	12.7%	13.9%	20.5%	20.4%
HUC_18010206	Upper Klamath	5.7%	5.7%	10.7%	10.4%
HUC_18010207	Shasta	3.5%	2.8%	4.8%	4.4%
HUC_18010208	Scott	5.5%	6.5%	8.7%	9.1%
HUC_18010209	Lower Klamath	-1.0%	-1.8%	-1.4%	-2.8%
HUC_18010210	Salmon	1.3%	1.4%	2.4%	1.8%
HUC_18010211	Trinity	0.8%	0.8%	1.1%	0.9%
HUC_18010212	South Fork Trinity	1.0%	0.1%	0.9%	-0.3%
Total Basin		9.0%	9.8%	14.1%	14.4%

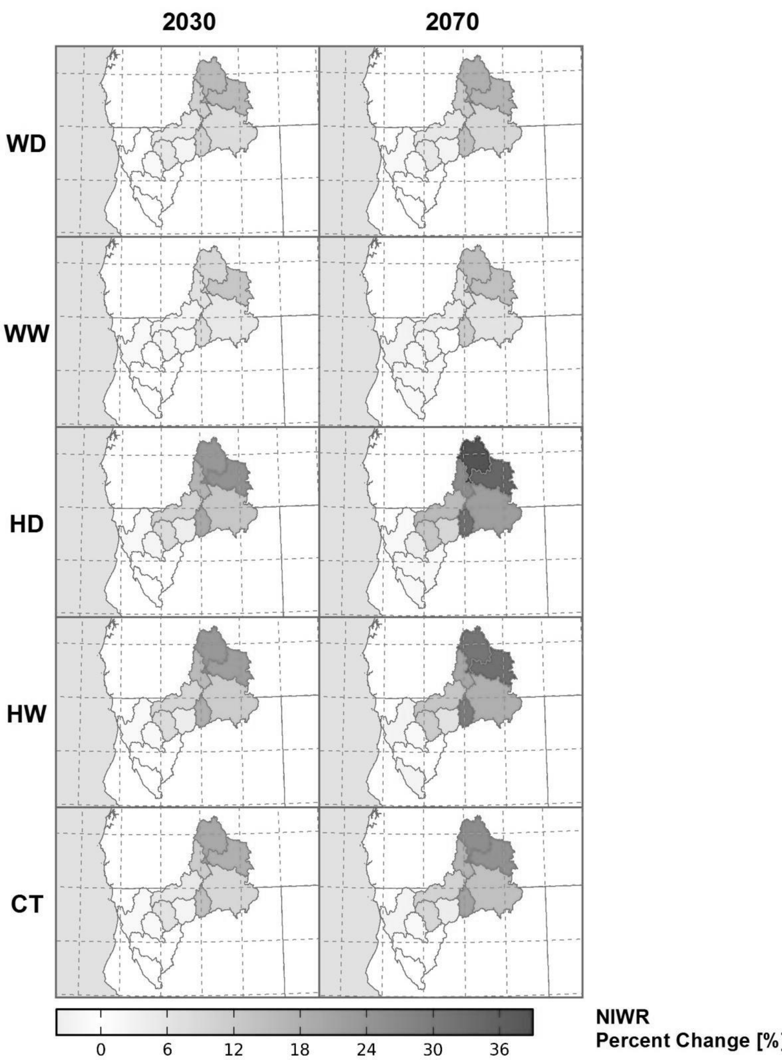

Figure 4-10. Klamath River Basin - Spatial distribution of projected net irrigation water requirements percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios)

17-01174_013157;17-01174_013157;17-01174_013158;17-01174_013159;17-01174_013160;17-01174_013161;1...

Figures 4-11, 4-12, and 4-13 illustrate the historical baseline and projected temporal distribution of mean daily ET_c for three perennial crops (alfalfa, pasture grass, and grass hay, respectively) under each CMIP5-based climate change scenario for the 2030s and 2070s. The values plotted in these figures are based on model results for Met Node OR4511 (NWS/COOP Klamath Falls Ag. Station).

Future Irrigation Demand Results

Assuming no change from current cropping patterns, the projected change in the central tendency scenario for the 2070s over the basin is 6-7% for reference ET (corresponding primarily to projected changes in temperature), while the projected change in crop ET is 10-11% (which incorporates changes in timing of crop growth and harvesting), and the projected change in NIWR is about 14% (which reflects changes in soil moisture throughout the year).

Figure 4-11 shows slight but noticeable shifts in the growing season length and alfalfa cutting cycles relative to historical baseline conditions by the 2030s (left). By the 2070s time period (Figure 4-11, right) significant shifts in growing season length, crop development, and cutting cycles are noticeable relative to baseline conditions, with the HW and HD scenarios exhibiting the most extreme changes. These simulations assume established crops rather than first year plantings. Projected changes in ET_c are primarily realized through earlier green-up of alfalfa hay and changes in its cutting pattern. Senescence of the crop is delayed somewhat, but is primarily driven by day length. Maximum mean daily ET_c during the warmest part of the year is not projected to increase substantially, primarily because plants have a maximum rate at which they can evapotranspire despite further increases in temperature.

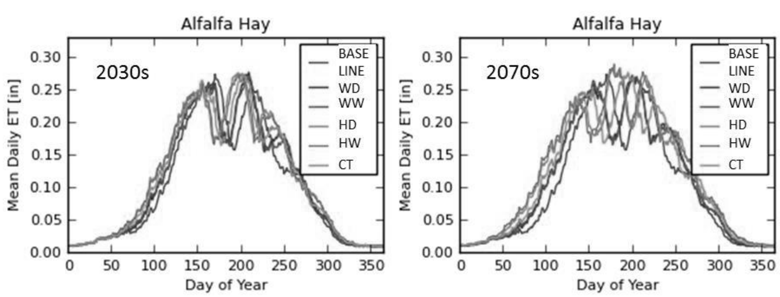

Figure 4-11. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily alfalfa evapotranspiration for all CMIP5-based scenarios and time periods

Figure 4-12 shows simulated mean daily ET_c of pasture grass; similar changes in green-up and increases in growing season length and ET_c are projected when compared to alfalfa, with the HW and HD scenarios having the most extreme seasonal changes.

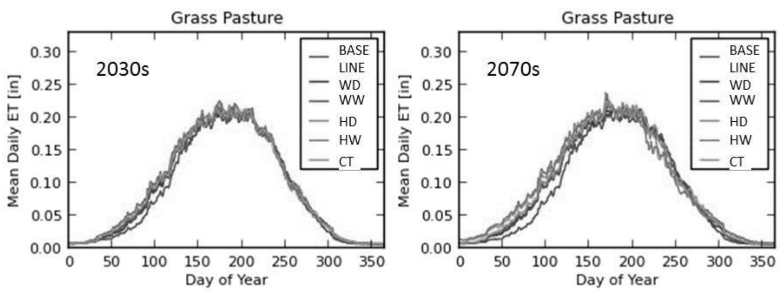

Figure 4-12. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily pasture grass evapotranspiration for all CMIP5-based scenarios and time periods

Figure 4-13 shows simulated mean daily ET_c of grass hay. As with alfalfa and pasture grass, earlier green-up and increased mean daily ET_c are slight for the 2030s and more pronounced for the 2070s. However, for the 2070s HW and HD scenarios, the overall growth period shifts forward rather than increasing in length. This is apparently due to the crop maturing earlier because of increased ET_c early in the growing season under higher temperatures.

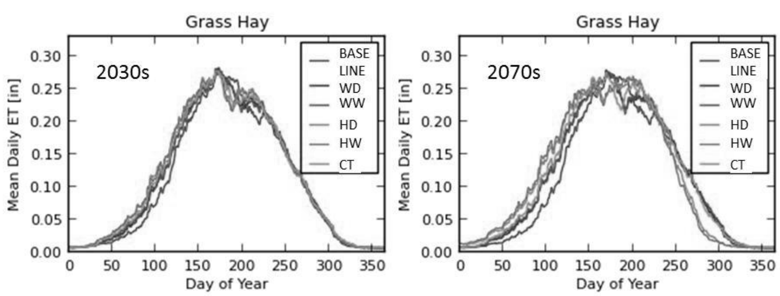

Figure 4-13. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily grass hay evapotranspiration for all CMIP5-based scenarios and time periods

Municipal and Industrial

Future M&I demand estimates are based on population growth projections and climate change scenarios. It is assumed current per capita demands will change as a function of changes in landscape irrigation demands due to climate change. Socio-economic factors that could cause changes in per capita demand, such as water conservation, reduced landscape areas, etc., are not accounted for in this chapter but are evaluated as potential adaptation strategies in Chapter 6. As previously discussed, 40 percent of total M&I use is assumed to be consumed through landscape irrigation.

The first step in estimating future M&I demands is to calculate the future base demands based on current demands and future population growth estimates (i.e., including growth scenario but no climate change scenarios). The base future demands are then adjusted for climate change effects on landscape irrigation. The adjustments were made using the same methods discussed previously for the future agricultural irrigation demand estimates. Specifically, the ET Demands model was used to calculate percent change in turf grass NIWR under the five climate change scenarios (WW, WD, CT, HW, and HD) using the two GCM projection datasets (CMIP3 and CMIP5). Forty percent of the base future demand estimate for a given period and scenario is increased based on the ET Demands model results.

The future M&I demand estimates for Klamath, Siskiyou, and Trinity Counties were calculated based on the 2005 USGS Water Use Program estimates and population growth rates published by the California Department of Finance[29] and Oregon Office of Economic Analysis.[30] Since the California and Oregon projections are for 2010 through 2060 and 2050 in five-year increments, respectively, it is assumed the growth rates from 2005 to 2015 are uniform as well for 2050–2070 (Oregon) and 2060–2070 (California). The product of the 2030 and 2070 county population growth rates and the 2005 county M&I estimates yields the base M&I demands for each county.

For the municipalities with domestic water supply systems in Del Norte, Humboldt, and Modoc Counties (Hoopa, Klamath, Newell, Orleans, and Willow Creek, all in California), county population growth rates published by the California Department of Finance were applied to the current (2010) population estimates for calculating future population estimates. The product of the 2030 and 2070 population projections and the current per capita demand estimates yields the base M&I demands for each of the systems in these municipalities.

As discussed above, each of the M&I base consumptive use estimates are adjusted for climate change. Figure 4-14 provides a summary of projected changes in M&I consumptive use for each county and each climate change scenario. The 2030 M&I consumptive use totals for all counties range from 9,759 AFY to

[29] http://www.dof.ca.gov/research/demographic/reports/projections/P-1/
[30] http://www.dof.ca.gov/research/demographic/reports/projections/P-1/

10,065 AFY and the 2070 estimate totals range from 11,003 AFY to 11,747 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

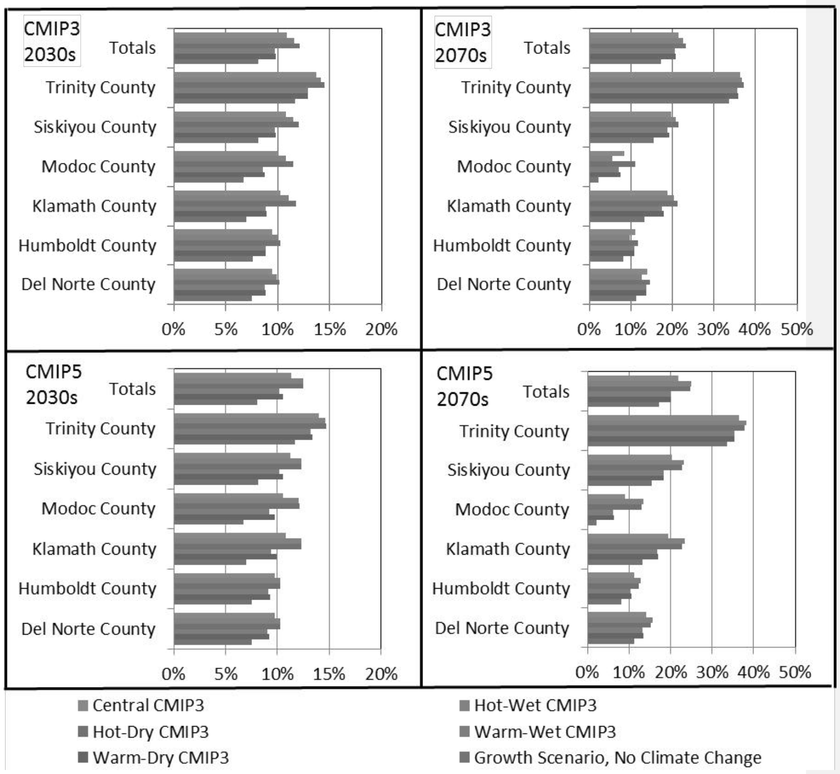

Figure 4-14. Summary of future municipal and industrial consumptive use estimates (percent change)

Rural Domestic

Future rural domestic water demand estimates were calculated based on population growth projections and climate change scenarios in the same manner as the M&I estimates discussed above. The same portion of total use for landscape irrigation is assumed (40 percent). Therefore, projections of future rural domestic use include only the consumptive portion of total use.

As discussed under Section 4.2, Current Demand, it is assumed the demands associated with the limited number of rural domestic water users in the portions of the basin in Del Norte and Humboldt Counties in California and Lake and

Jackson Counties in Oregon are negligible. Estimates were therefore calculated for Modoc, Siskiyou, and Trinity Counties in California and Klamath County in Oregon. The population projections used in the calculations are based on the 2005 USGS Water Use Program information and county population projections published by the California Department of Finance and Oregon Office of Economic Analysis.

Figure 4-15 provides a summary of projected change in rural domestic consumptive use for each county and each climate change scenario. The 2030s estimate totals for all counties range from 5,013 AFY to 5,190 AFY and the 2070s estimate totals range from 5,644 AFY to 6,030 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

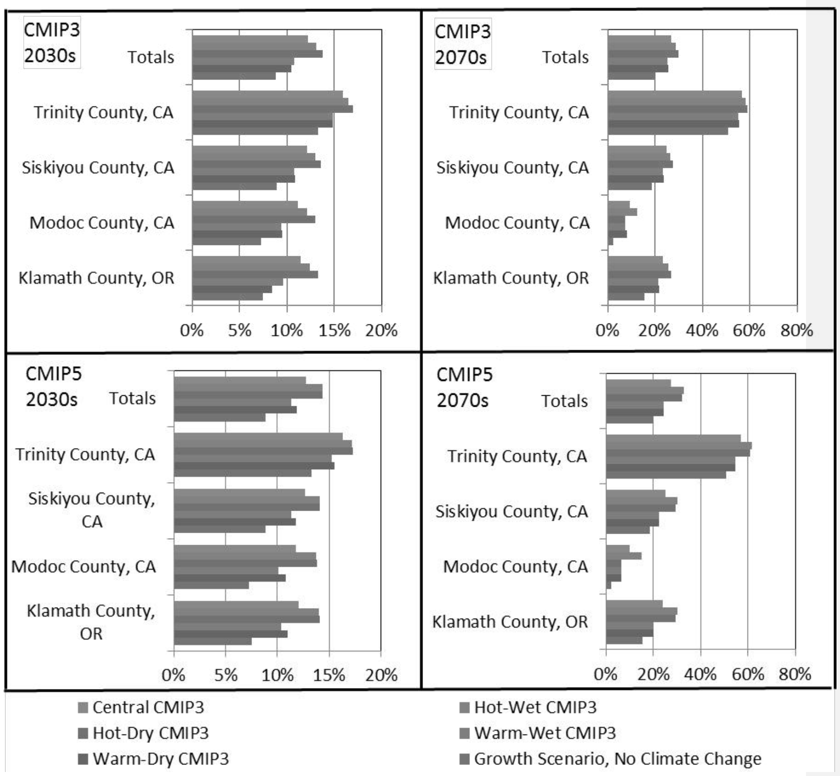

Figure 4-15. Summary of future rural domestic consumptive water use estimates (percent change)

4.3.3.2 Wetlands

Future wetland ET was computed based on projected mean daily alfalfa ET and pasture ET, using the same approach defined in Section 4.21, Human Influenced Consumptive Uses–Wetlands. Climate change scenarios using the HDe approach for each of the five quadrants of change for the 2030s and 2070s (using both CMIP3- and CMIP5-based projections) were also incorporated. The same relationships between wetland ET and alfalfa and pasture ET, according to the findings of Stannard et al. (2013), were used to determine projected mean annual wetland ET. Wetland ET is about 7 percent less than alfalfa ET during its average growing season and wetland ET is also about 18 percent greater than pasture ET during its average growing season. Mean annual wetland ET was computed using both relationships and averaged together for a single estimate.

Table 4-22 provides a summary of the resulting future wetland ET for each climate change scenario. The 2030s estimates range from 1,144,230 AFY to 1,228,916 AFY and the 2070s estimates range from 1,192,224 AFY to 1,319,673 AFY, compared with 1,089,061 AFY estimated for the mean annual historical wetland ET.

Table 4-22. Summary of basin-wide projected changes in wetlands ET

Future Period and Scenario	Mean Annual Wetland ET (AFY)	Mean Annual Wetland ET (Percent Change)
Historical	1,089,061	-
2030 Warm-Dry CMIP3	1,144,230	5%
2030 Warm-Dry CMIP5	1,155,489	6%
2030 Warm-Wet CMIP3	1,146,443	5%
2030 Warm-Wet CMIP5	1,163,648	7%
2030 Hot-Dry CMIP3	1,205,813	11%
2030 Hot-Dry CMIP5	1,228,916	13%
2030 Hot-Wet CMIP3	1,202,385	10%
2030 Hot-Wet CMIP5	1,225,025	12%
2030 Central CMIP3	1,175,143	8%
2030 Central CMIP5	1,191,936	9%
2070 Warm-Dry CMIP3	1,208,198	11%
2070 Warm-Dry CMIP5	1,192,224	9%
2070 Warm-Wet CMIP3	1,219,044	12%
2070 Warm-Wet CMIP5	1,203,335	10%
2070 Hot-Dry CMIP3	1,260,874	16%
2070 Hot-Dry CMIP5	1,300,472	19%
2070 Hot-Wet CMIP3	1,271,150	17%
2070 Hot-Wet CMIP5	1,319,673	21%
2070 Central CMIP3	1,237,064	14%
2070 Central CMIP5	1,246,884	14%

4.3.3.3 Lake and Reservoir Evaporation

The previously discussed CRLE model that was used to estimate historical baseline average evaporation rates was also used to estimate future average rates for the 2030s and 2070s periods. The same HDe climate change scenarios temperature and precipitation data described under the future agricultural irrigation demands discussion were input to the model. The model results include mean monthly evaporation and net evaporation (evaporation minus precipitation) rates for all of the reservoirs included in Table 4-14. The results for Upper Klamath Lake and Clair Engle Lake are discussed below, and the results for the other reservoirs are included in Appendix C, Section 5.0

Figures 4-16 and 4-17 show Upper Klamath Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and the historical baseline (1950–1999). The simulated impact of heat storage is negligible due to the shallow depth of Upper Klamath Lake. The magnitude of projected monthly evaporation and net evaporation increase is greatest during July, and least during fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Upper Klamath Lake is 5.5 and 5.4 percent (2.4 and 1.1 inches). Values for all scenarios are included in Appendix C, Section 5.0.

Figures 4-18 and 4-19 show Clair Engle Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and historical baseline (1950–1999). The simulated impact of heat storage due to the depth of Clair Engle Lake can be seen in the lag in peak evaporation relative to peak air temperatures (August versus July). Also, the relatively high precipitation rates result in negative net evaporation under all scenarios and the historical baseline. The magnitude of projected monthly evaporation and net evaporation increase is greatest during August, and least during the fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Clair Engle Lake is 5.7 and 9.0 percent (2.3 and -2.3 inches), respectively. Values for all scenarios are included in Appendix C, Section 5.0.

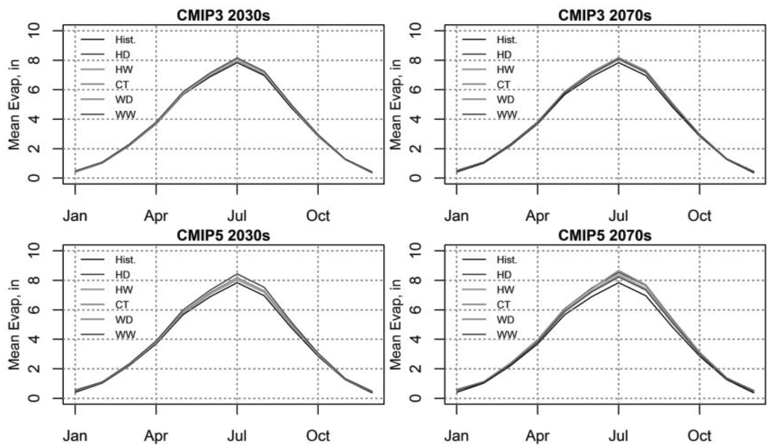

Figure 4-16. Summary projected mean monthly evaporation at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

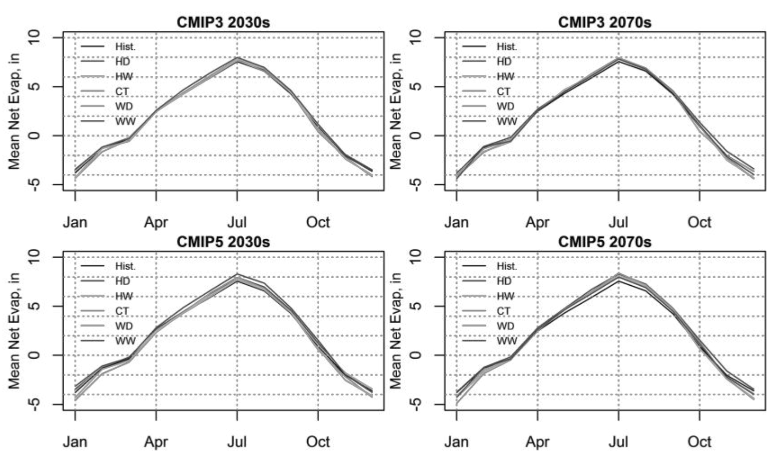

Figure 4-17. Summary projected mean monthly net evaporation (evaporation – precipitation) at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

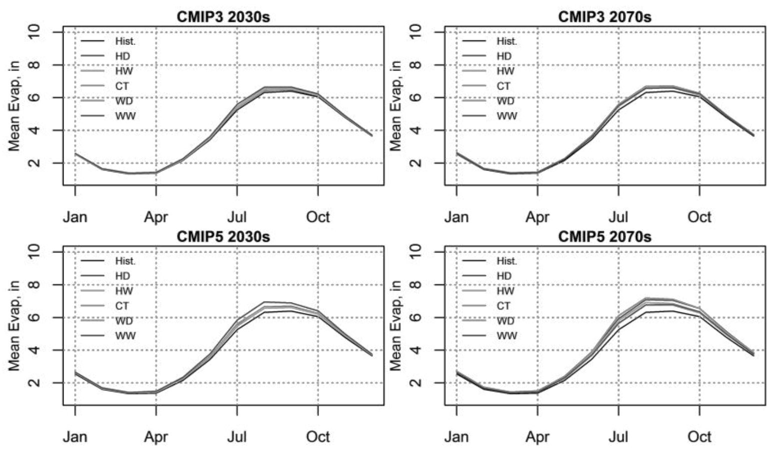

Figure 4-18. Summary projected mean monthly evaporation at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

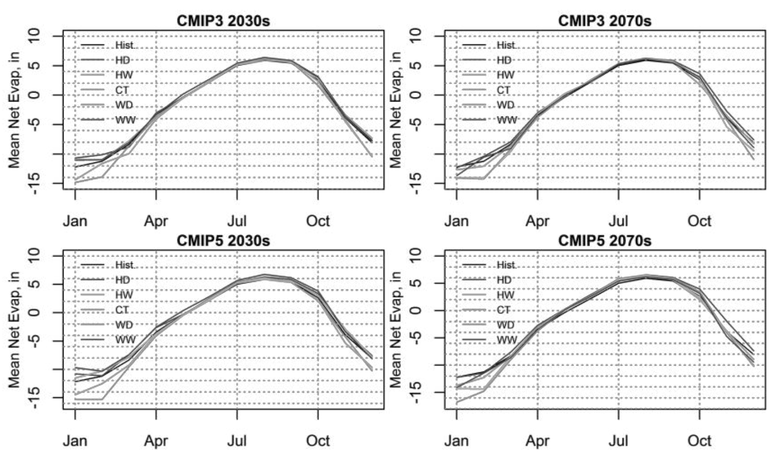

Figure 4-19. Summary projected mean monthly net evaporation (evaporation – precipitation) at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

4.3.3.4 Non-Consumptive Uses

The effects of climate change on these uses (including recreation, environmental resources, hydropower, and aquaculture) are evaluated as part of the system reliability analysis in Chapter 5. In Chapter 5, the impacts are discussed in terms of factors such as exceedance of water quality criteria, flow or water level targets, and loss of power generation due to changing flows.

4.4 Uncertainties Associated with Impacts Assessment Approach

The Chapter 3 discussions on uncertainties associated with the various aspects of the Klamath River Basin Study water supply assessment covered many topics that also apply to the demands assessment. These topics include global climate forcing and simulation, climate projection bias correction and spatial downscaling, and climate projections from CMIP3 and CMIP5. Brief discussions of the limitations and uncertainties associated with quantification of water demands are presented below. A detailed discussion of uncertainties associated with the models used to estimate net irrigation water requirements (ET Demands) and reservoir evaporation (CRLE) are presented in Reclamation (2015) and are not detailed here.

Commented [GIM5]: I would add something here in light of the revised discussion in Section 3.9

4.4.1 Agricultural Irrigation

There are numerous uncertainties and limitations in modeling reference ET, crop ET, and net irrigation water requirements. One source of uncertainty is associated with underlying assumptions in modeling, such as static cropping patterns and farming practices. This study uses data provided by Reclamation's Klamath Basin Area Office for Klamath Project lands and the USDA crop land data layer for the remainder of the basin as the sources for quantifying the types of crops grown in the Klamath River Basin. It is assumed these crop types and quantities do not change in the modeling. Obviously, increases or decreases in the overall amount of irrigated area would result in respective changes in demands. Changes in crop choice may significantly affect future agricultural demands given the variability in water demand for different crop types.

Another source of uncertainty is the weighted average soil conditions used in the estimation of net irrigation water requirements. Precipitation runoff and soil water holding capacity are a function of soil type, and soil types can vary significantly even within a single irrigated parcel of land. The degree of uncertainty in the method used depends on the variability of soil types within each HUC8 subbasin for which a weighted average soil type was calculated, as described in Reclamation (2015).

Climatic data used in this basin study analysis were limited to daily maximum and minimum temperatures and daily precipitation; therefore solar radiation, humidity, and windspeed were approximated for baseline and future time periods using empirical approaches. Solar radiation was simulated for baseline and future

periods based on empirical relationships of differences between daily maximum and minimum air temperatures, where maximum air temperature generally decreases during cloud cover, and minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night. Integration of potential changes in solar radiation, and evaluating the potential impact of such changes on irrigation water demands, were not addressed in this analysis.

Historical agricultural weather station data were used to estimate the spatial distribution of baseline and projected mean monthly dewpoint depression and windspeed. Given the uncertainties and limited availability in future projections of humidity and windspeed, mean monthly dewpoint depression and windspeed were considered static for future periods. While there is considerable uncertainty in projecting future reference ET, estimation of reference ET for historical periods using the assumptions outlined above was shown to be robust when compared to agricultural weather station estimated reference ET.

4.4.2 Municipal and Industrial and Rural Domestic

Uncertainties associated with M&I and rural domestic demands are related to the assumed population projections and per capita demand rates used, and the assumed landscape irrigation portion of the overall demand (40 percent).

4.4.3 Wetlands

Evapotranspiration from wetlands is difficult to quantify and a limited number of studies have been conducted in this area of research. Wetlands are biologically diverse and quantification of ET requires expensive long-term monitoring. Existing studies often based their findings on data collected over a limited time period, generally a few years, contributing to the uncertainty around their estimates. The Klamath River Basin Study utilizes available studies to estimate mean annual wetland ET. Although there is relatively high uncertainty surrounding the estimates of wetland ET in this study, they generally corroborate other existing studies and provide a best estimate of mean annual wetland ET.

4.4.4 Reservoir Evaporation

Uncertainties in estimated reservoir evaporation are largely centered on CRLE energy balance considerations, specifically heat storage and advection of heat in air and water into and out of the reservoir. One important limitation of the CRLE model is its reliance on energy balance without consideration of the effects of windspeed on evaporation. However, one could argue that using an approach that heavily relies on windspeed, and is therefore extremely sensitive to uncertainties in windspeed (i.e., the aerodynamic-mass transfer or combination approach), may actually increase evaporation uncertainty, especially under future climates where projections of near surface local scale windspeed estimates are extremely uncertain.

It is significant that reservoir evaporation and net evaporation (evaporation minus precipitation) demands were estimated in terms of annual rates or depths rather

than volumes. These rates were estimated based on average historical conditions and a more rigorous analysis would be required to model evaporation under predicted future reservoir conditions. Future research in the Klamath River Basin could involve adjusting the CRLE model to accommodate projections of future reservoir conditions.

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Chapter 5
Klamath River Basin Study
System Reliability Analysis

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Chapter 5
System Reliability Analysis

5.1 Introduction

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to work toward future water security. Reclamation developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (P.L. 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management. Studies are typically completed within a three-year timeframe. The purpose of the Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances.

This chapter discusses the methodology for evaluating gaps in water supply and demand and summarizes the reliability of the Klamath River system in achieving numerous defined measures, based on both historical data and projected future conditions.

Previous chapters of the Basin Study include an introduction and background for the study (Chapter 1), a discussion of various interrelated activities in the watershed (Chapter 2), an assessment of historical and future water supply in the watershed (Chapter 3), and an assessment of historical and future water demand in the watershed (Chapter 4). Chapter 6 discusses the development and evaluation of adaptation strategies for reducing gaps in water supply and demand within the system reliability framework discussed in this chapter. Figure 5-1 provides an overall schematic of the Basin Study approach to provide context for Chapter 5.

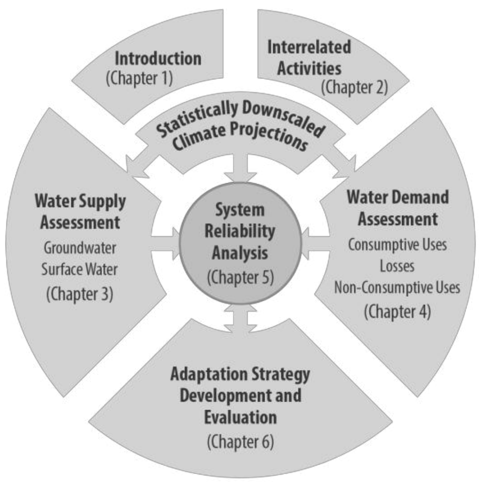


Figure 5-1. Overall approach of Klamath River Basin Study, highlighting Chapter 5

5.2 System Reliability Methodology

The Basin Study developed a framework for evaluating projected future water supply and demand conditions in a changing climate. This framework includes scenarios for characterizing projected future conditions, along with development and implementation of connected modeling components, with the end goal of evaluating system risk and reliability in the basin. Additionally, the Basin Study system risk and reliability analysis evaluates impacts of climate change on non-consumptive uses, which are those that do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.) and water needs to support fish and wildlife and hydropower production, among others.

This section briefly reviews the scenarios developed and corresponding modeling components implemented to provide inputs to a water management model. More detailed discussions of historical and projected water supply and demand are provided in Chapters 3 and 4, respectively. This section then provides a detailed description of the tools developed to evaluate system reliability and potential vulnerabilities to climate change impacts. Results from the analysis are evaluated using basin-wide response variables and defined measures to quantify and summarize projected changes in system reliability due to climate change.

5.2.1 Characterizing Historical and Future Conditions

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020–2049) and the 2070s (represented by the mean from 2060–2089). Future projections are compared with a historical reference period of 1950–1999 to evaluate the effects of climate change on water supply.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. The same dataset was used for analysis of historical conditions in the Basin Study. Historical trends in April 1 SWE, total annual runoff, total annual ET, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model (described in detail in Chapter 3).

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50 year period). All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999. Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide. Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent. ET, as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide. Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole. The only statistically significant trend at the 95th percentile level computed with the historical data is mean annual temperature.

The development of climate change scenarios is described in Chapter 3, Section 3.5.1.1 Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). The Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes available climate projections to derive a smaller number of climate change scenarios to inform long term planning. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios for each of two sets of projections (CMIP3 and CMIP5). These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT). These scenarios were derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d).

Projections of future water supply and demand using the above-discussed climate change scenarios and evaluated in Chapters 3 and 4, respectively, are briefly summarized below. Following this brief summary is a discussion of the methodology used to evaluate projected changes in managed streamflow and water temperature at various locations throughout the basin.

5.2.1.1 Water Supply

- By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.
- Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.
- A decrease in April 1 SWE is projected on the order of 34 to 40 percent for the 2030s and close to 60 percent for the 2070s, and projected increases in annual runoff are 7 to 12 percent for the 2030s and 14 to 15 percent for the 2070s. Projected increases in mean annual runoff are offset by projected changes in April 1 SWE, primarily due to projected increases in mean annual precipitation,
- For sub-basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.
- An increase in groundwater head is projected in mountainous recharge areas of the Upper Klamath Basin (less than 9 percent), as is a change in groundwater discharge to streams, while little change is expected in populated interior parts of the basin.

5.2.1.2 Water Demands (Human Influenced)

- Agricultural irrigation demand (surface and groundwater) is the largest human influenced consumptive use in the basin.
- Projected changes in total consumptive uses are 12 or 13 percent (CMIP3 and CMIP5 scenarios, respectively) for the 2030s and 17 or 18 percent for the 2070s. Consumptive uses include agricultural irrigation, net reservoir evaporation, municipal and industrial (M&I) and rural domestic demands, and wetlands.
- The effects of climate change on other non-consumptive uses including recreation, environmental resources, hydropower, and aquaculture are evaluated as part of this chapter.

5.2.2 Basin-Wide Responses

The evaluation of climate change impacts on system risk and reliability has two primary components: basin-wide system response at various basin locations, and specific performance measures that have been identified through discussions with regional resource managers, stakeholders, and others. Evaluation of basin-wide system response provides a general understanding of projected changes in managed conditions as a result of climate change and implemented adaptation strategies. Evaluation of system response to quantified measures provides a deeper understanding of climate change impacts on specific resources relevant to water management in the basin.

Basin-wide response variables include mean monthly conditions for the following locations:

- Mean monthly Upper Klamath Lake storage
- Mean monthly inflow to Klamath River at Keno
- Mean monthly streamflow, Klamath River at Iron Gate
- Mean monthly streamflow, Klamath River at Orleans, California
- Mean monthly streamflow, Klamath River near Klamath, California
- Mean monthly water temperature in the Klamath River near Klamath, California

This report includes analysis of historical and projected future changes in these basin-wide response variables, according to the developed Basin Study modeling framework. Subsequently, in Chapter 6, basin-wide response variables are evaluated for each of the adaptation strategies selected for exploring ways to reduce any identified water supply and demand gaps. Performance measures are described in more detail below.

5.2.3 Performance Measures

Performance measures are used to evaluate historical and future vulnerabilities to meeting water needs in the basin, and to facilitate the comparison of adaptation strategies to reduce any identified imbalances in water supply and demand.

Performance measures have been identified in accordance with the Basin Study Framework guidance document (Reclamation, 2009c) and span numerous resource categories, which include:

- Water deliveries – the ability for water to be delivered to water users
- Hydroelectric power resources
- Recreational resources – including Reclamation facilities and parts of the watershed impacted by Reclamation operations

- Ecological resources – including fish and wildlife habitat; applicable species listed as an endangered, threatened, or candidate species under the Endangered Species Act of 1973; species and habitat of cultural importance; and flow and water dependent ecological resiliency
- Water quality resources
- Flood control

Measures for each category were arrived at based on input from stakeholders and resource managers in the basin. Table 5-1 summarizes the performance measures. The following paragraphs describe each measure in more detail.

Table 5-1. General description of performance measures

Resource Category	Measure Description	Location(s)	Measure Details
Water supplies	Total Klamath Project supply	Klamath Project	Calculated under 2013 Biological Opinion operating criteria. Compare result with full season Klamath Project supply of 390,000 acre-feet.
	Total Upper Klamath Lake seasonal supply	Upper Klamath Lake	End of February storage plus actual March through September inflow at Upper Klamath Lake
	Mean annual tributary flow	Shasta River; Scott River	Mean annual flow at USGS gages (USGS 11517500 Shasta River near Yreka; USGS 11519500 Scott River near Fort Jones)
Hydroelectric power resources	Hydropower production	Sum of J.C. Boyle power, COPCO 1 power, COPCO 2 power, Iron Gate power	Mean annual hydropower production summed over these facilities[31]
	Volume of spill	J.C. Boyle, COPCO 1, Iron Gate	Mean annual spill volume based on water year[1]
	Frequency of spill	J.C. Boyle, COPCO 1, Iron Gate	Mean number of spill days per water year at these facilities[1]
Recreational resources	Mean fishing days per year	Various mainstem Klamath River reaches	Mean number of days per year that flows are within acceptable ranges for select river reaches

[31] Source: PacifiCorp

Table 5-1. General description of performance measures

Resource Category	Measure Description	Location(s)	Measure Details
	Mean boating days per year	Various mainstem Klamath River reaches	Mean number of days per year that flows are within acceptable ranges for select river reaches
Ecological resources	Salmonid success	Shasta River; Scott River	Flow thresholds throughout the year[32]
	Delivery to refuge	Lower Klamath National Wildlife Refuge	Mean annual water delivery to refuge[33]
	Pool elevation	Clear Lake; Gerber Reservoir	Minimum elevation thresholds[34]
Water quality	Water temperature	Klamath River	Maximum weekly average temperature (MWAT)
Flood control	Frequency of flood control release	Upper Klamath Lake	Mean number of days per year that flood control releases are made from Upper Klamath Lake[35]
	Mean annual flood control release volume	Upper Klamath Lake	Mean annual volume of flood control releases from Upper Klamath Lake[5]
	Date of seasonal peak flow	J.C. Boyle, COPCO 1, Iron Gate	Mean date of the center of mass of the annual flow volume (by water year) at select locations[1]

5.2.3.1 Water Supplies – Klamath Project Water Supply

There are two measures associated with Klamath Project water supply. The first measure is computed as the mean annual water supply to the Klamath Project, expressed as a percentage. The value may be compared with a full supply quantified as 390,000 acre-feet.

The second measure is computed as the sum of the end of February Upper Klamath Lake storage and the actual March through September Upper Klamath Lake inflow, averaged across the simulation years and expressed in units of a thousand acre-feet. The measure represents the total seasonal availability of water supply to be distributed among project responsibilities.

5.2.3.2 Water Supplies – Mean Annual Tributary Flow in Shasta and Scott Rivers

This measure is computed for two locations: USGS gages Shasta River near Yreka (11517500) and Scott River near Fort Jones (11519500). The measure is computed as the mean annual streamflow at these two locations. Effectively, the simulated streamflows represent the balance of supply and demand in these two

[32] Source: McBain and Trush (2014)
[33] Source: Klamath Basin National Wildlife Refuge Complex
[34] Source: Klamath Basin Area Office
[35] Source: Reclamation (2012d)

tributary watersheds to the Klamath River. Units are in cubic feet per second (cfs).

5.2.3.3 Hydroelectric Power Resources – Hydropower Production
This measure is computed as the sum of mean annual hydropower production at J.C. Boyle reservoir, COPCO 1 reservoir, COPCO 2 reservoir, and Iron Gate reservoir. Units of hydropower production are megawatts.

5.2.3.4 Hydroelectric Power Resources – Spill Volume
This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean spill per year in cfs.

5.2.3.5 Hydroelectric Power Resources – Spill Frequency
This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean number of days per year that each of the reservoirs have spill.

5.2.3.6 Recreational Resources – Mean Annual Fishing Days
This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow (by the surface water management model) is within the target ranges for fishing in each river reach. Table 5-2 lists the recommended flow ranges for fishing.

Table 5-2. Recommended target flow ranges for fishing within select reaches of the Klamath River

River Reach	Flow Target Ranges (cfs)
Keno Reach	200-1,500
J.C. Boyle	200-1,000
Hell's Corner Reach	200-1,500
COPCO 2 Bypass Reach	50-600
Iron Gate to Scott River	800-4,000
Scott River to Salmon River	800-4,000
Salmon River to Trinity River	800-10,000
Trinity River to ocean	1,000-18,000

Source: Interior and CDFG, 2012

5.2.3.7 Recreational Resources – Mean Annual Boating Days
This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow by the surface water management model is within the target ranges for river boating in each river reach. Table 5-3 lists the recommended flow ranges for river boating.

Table 5-3. Recommended target flow ranges for boating within select reaches of the Klamath River

River Reach	Flow Target Ranges (cfs)
Keno Reach	1,000-4,000
J.C. Boyle	1,300-1,800
Hell's Corner Reach	1,000-3,500
COPCO 2 Bypass Reach	600-1,500
Iron Gate to Scott River	800-4,000
Scott River to Salmon River	800-7,000
Salmon River to Trinity River	800-10,000
Trinity River to ocean	1,000-18,000

Source: Interior and CDFG, 2012

5.2.3.8 Ecological Resources – Salmonid Success in Shasta and Scott Rivers

This measure is computed at two locations: USGS gages Scott River near Fort Jones (11519500) and Shasta River near Yreka (11517500). The measure compares simulated daily flow to quantified dry year flow targets recommended by McBain and Trush (2014) for the Shasta River. A dry year has an exceedance probability of between 61 and 100 percent. The measure is computed as the total number of days in a model simulation that dry year flow targets are met or exceeded, divided by the total number of days in the simulation and presented as a percentage. Dry year flow targets recommended by McBain and Trush (2014) are summarized below in Table 5-4. Note that the flow targets were developed for the Shasta River, where mean annual flow (188 cfs) is less than one third that of the Scott River (669 cfs). However, for purposes of this analysis the same threshold flows were applied for the Scott River to explore the frequency of meeting those same target flows in the Scott River.

Table 5-4. Dry Year (61–100 percent exceedance) flow targets for salmonids

Time Period	Dry Year Target (cfs)
January 1 – March 31	135
April 1 – May 15	170
May 16 – June 15	150
June 16 – September 15	70
September 16 September 30	70-90
October 1 – October 16	125
October 17 – October 30	125-150
October 31 – December 31	150

Source: McBain and Trush 2014

5.2.3.9 Ecological Resources –Water Delivery to Lower Klamath National Wildlife Refuge

This measure is computed as the mean annual water supply to Lower Klamath National Wildlife Refuge as simulated by the surface water management model. The measure is expressed in acre-feet.

5.2.3.10 Ecological Resources – Pool Elevation at Clear Lake and Gerber Reservoirs
This measure is computed at two locations: Clear Lake and Gerber Reservoirs. The measure compares simulated pool elevations at these locations with minimum pool elevations quantified for survival of Lost River and shortnose suckers. Minimum pool elevation for Clear Lake is 4,520.6 feet, while the minimum pool elevation for Gerber Reservoir is 4798.1 feet. The measure is computed as the mean percent of days that simulated pool elevations are at or above target pool elevations.

5.2.3.11 Water Quality – Water Temperature
This measure is computed as the maximum weekly average temperature (MWAT) in the mainstem Klamath River. The MWAT is the highest seven-day moving average of the daily mean river temperature. This measure is computed using the RBM10 stream temperature model developed by Perry et al. (2011). Details of the river temperature modeling approach and implementation are discussed in Section 5.3.2, System Reliability Model Development – Water Temperature Model. The MWAT is computed for each year and the mean of these temperatures across the simulation years is presented as the measure. Table 5-5 summarizes classifications of Poor to Very Good conditions for fish, along with associated temperature ranges, provided in the SONCC ESU coho salmon recovery plan (NMFS 2012).

Table 5-5. Maximum weekly average temperature recommendations from the SONCC ESU salmon recovery plan

Maximum Weekly Average Temperature (MWAT) Classification	Temperature Range (degrees C)	Temperature Range (degrees F)
Poor	> 17.6	> 63.68
Fair	16-17	60.8-62.6
Good:	15-16	59-60.8
Very Good	< 15	< 59

Source: NMFS 2012, Appendix B

5.2.3.12 Flood Control – Flood Control Release Frequency
This measure is computed as the mean annual percent of days where release from Upper Klamath Lake is specifically for flood control purposes. The unit of the measure is percent of days.

5.2.3.13 Flood Control – Flood Control Release Volume
This measure is computed as the mean annual volume of releases from Upper Klamath Lake specifically for flood control purposes. The unit of the measure is thousands of acre-feet (KAF).

5.2.3.14 Flood Control – Date of Seasonal Peak Flow
This measure is computed as the mean date of the center of mass of the annual flow volume (by water year) at select locations. The center of mass is defined as

the time at which half of the mean annual flow has passed the location of interest. The measure is presented as the mean date over the simulation period.

5.3 System Reliability Model Development

This analysis utilizes developed historical and future water supply and demand as input to a system risk and reliability model framework. The modeling framework involves two main components: the implementation of a surface water management model to generate simulated managed streamflow throughout the basin, and the implementation of a river temperature model to generate simulated water temperature in the mainstem Klamath River. The modeling components are described below in more detail.

5.3.1 Surface Water Management Model

A RiverWare surface water management model (Zagona et al., 2001) was developed for use by the Klamath River Basin Study. The RiverWare software platform allows for evaluation of river flows based on rule-based operations, using logic statements and assigned rule priorities. The RiverWare platform has been used in many other studies conducted by Reclamation and others (e.g., Colorado River Basin Water Supply and Demand Study [Reclamation, 2012e]; St. Mary River and Milk River Basins Study [Reclamation, 2012f]).

The Klamath Basin RiverWare model is a daily timestep model based on two existing models for the Upper Klamath Basin and Lower Klamath Basin. The existing Upper Klamath Basin model, commonly referred to as the Klamath Basin Planning Model (KBPM), was developed to support the ESA consultations over the impacts of Klamath Project operations on the endangered SONCC ESU coho salmon (Reclamation, 2012d). The existing Lower Klamath Basin model was developed to support the environmental impacts assessment for removal of four of the mainstem Klamath River dams (Interior, Department of Commerce, NMFS, 2012).

The Klamath Basin RiverWare model encompasses the entire watershed including tributaries of Upper Klamath Lake, the Lost River system, and major Klamath River tributaries such as the Shasta River, Scott River, Indian Creek, Salmon River, and Trinity River. The model includes representation of eight reservoirs: Upper Klamath Lake, Clear Lake, Gerber Reservoir, Lake Ewauna, J.C. Boyle Reservoir, COPCO 1 Reservoir, COPCO 2 Reservoir, and Iron Gate Reservoir.

The Klamath Basin RiverWare model was developed over a historical time period of water years 1961 through 2013 to facilitate comparison of results with the KBPM model. The historical model incorporates historical water demand information, and simulated water supply information from the water supply assessment in Chapter 3 in order for model validation to be performed. Once simulated flows were reached that sufficiently compared with results from the KBPM model, a separate historical model was developed using a period of record

of water years 1969 through 1999. The latter model incorporates simulated historical information from the water supply and water demands assessments in Chapters 3 and 4, respectively. This model was used as the basis for comparison of simulated streamflows under the historical climate to those under climate change scenarios.

The level of detail of the Klamath Basin RiverWare model allows for evaluation of Klamath River flows and Klamath Project operations under the current 2013 non-jeopardy Biological Opinion for SONCC ESU coho salmon, as well as evaluation of climate change impacts on other parts of the basin, including the Lost River and major Klamath River tributaries listed above.

Inputs to the Klamath Basin RiverWare model include the following:

- simulated natural surface hydrology from the VIC hydrologic model at various locations within the basin
- simulated groundwater discharge to streams in the Upper Klamath Basin as produced by the Gannett et al. (2007) MODFLOW model
- agricultural irrigation water requirements by 8-digit hydrologic unit code (HUC) throughout the Klamath Basin as produced by the water demands assessment (Chapter 4)
- net reservoir evaporation rates as produced by the water demands assessment (Chapter 4)
- M&I and rural domestic demands as produced by the water demands assessment

Outputs from the Klamath Basin RiverWare model include the following:

- Simulated managed flow at various locations in the Klamath Basin
- Reservoir storage and elevations
- Deliveries to the Klamath Project, Lower Klamath National Wildlife Refuge (LKNWR), etc.
- Hydropower generation

5.3.2 Water Temperature Model

The Klamath River Basin Study incorporates analysis of historical and projected future Klamath River temperature using an existing river temperature model developed by Perry et al. (2011). The river temperature model, called River Basin Model-10 (RBM10), was developed for the Secretarial Determination on removal of four hydroelectric dams on the Klamath River. It simulates water temperatures in the mainstem Klamath River from the Link River to the mouth. In this

application, water temperatures are computed at the Klamath River near Klamath, California.

RBM10 uses a simple equilibrium flow model, assuming discharge in each river segment on each day is transmitted downstream instantaneously. The model uses a heat budget formulation to quantify heat flux at the air-water interface. Inputs for the heat budget were calculated from daily-mean meteorological data including net shortwave solar radiation, net longwave atmospheric radiation, air temperature, wind speed, vapor pressure, and a psychrometric constant needed to calculate the Bowen ratio.

For the Klamath River Basin Study application, meteorological inputs used as part of the water supply assessment described in Chapter 3 were adjusted to match the statistics of the meteorological data used by Perry et al. (2011) in their study of the impacts of climate change and dam removal on Klamath River water temperatures. Input streamflows were taken directly from the Klamath Basin RiverWare model at locations consistent with the Perry et al. (2011) study. It should be noted that input streamflows were increased by 10 cfs in some Upper Klamath Basin reaches to prevent negative streamflows in the mainstem Klamath River. Negative Klamath River flows were possible due to the difference in handling of streamflow routing by the RBM10 and Klamath River Basin RiverWare models.

5.4 System Reliability and Impacts Assessment

Historical and projected future reliability of the Klamath River Basin water supply is summarized in two ways: through basin-wide response variables, and through identified reliability measures that were defined for six resource categories. This methodology was previously described in Section 5.2, System Reliability Methodology.

This chapter summarizes historical and projected changes in system reliability due to climate change alone. Chapter 6 discusses how various basin-wide responses and select measures may change as a result of implementing adaptation strategies.

Impacts on Reservoir Storage

Mean end of month storage in Upper Klamath Lake generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, end of month reservoir storage did not historically fluctuate substantially through the year. Projections for the 2030s and 2070s indicate peak storage is likely to remain about the same or increase slightly.

5.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of historical and projected future basin-wide responses to water supply and demand allows for a general understanding of how the basin may respond as a result of climate change. Historical and projected future changes in water availability of the managed Klamath River system are provided below. Data supporting the following figures are provided in Appendix D.

5.4.1.1 Upper Klamath Lake Storage

Mean monthly end of month (EOM) storage in Upper Klamath Lake is summarized in Figure 5-2. Maximum storage historically occurs at the end of May, while minimum storage occurs in November. Under the climate change scenarios, mean EOM storage generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s, or even two months under the HW scenario. In addition, all scenarios experience a deeper drawdown of Upper Klamath Lake (UKL) than under simulated historical conditions and show minimum elevations in October compared to November (historical). Results in Figure 5-2 show that projected mean EOM storage is less under all future scenarios than under the simulated historical reference period. This result is likely due to use of the 2013 BiOp management criteria for all scenarios. Many management decisions rely on static look-up tables, which lack the flexibility to respond to different hydrologic conditions such as changes in Upper Klamath Lake inflow timing.

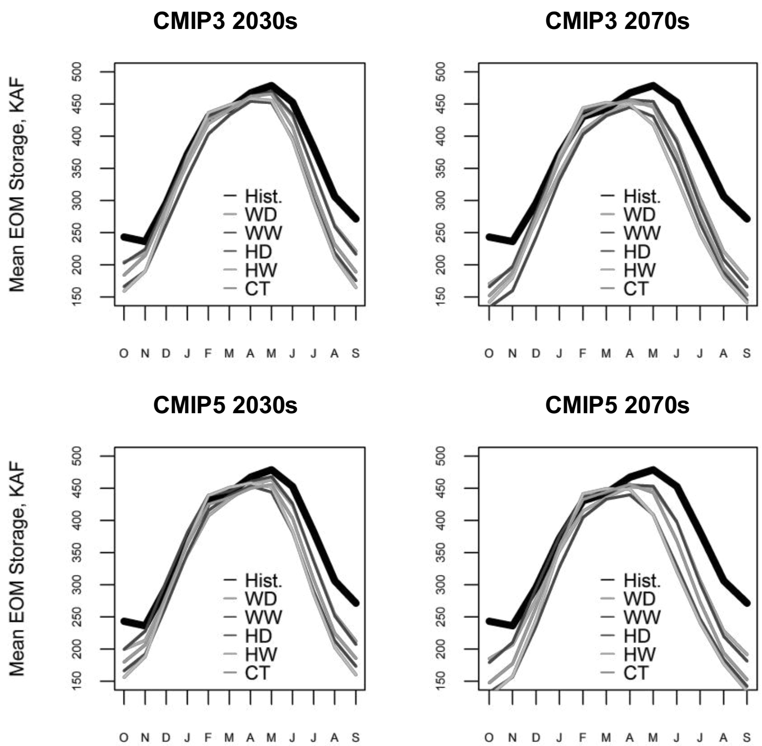


Figure 5-2. Historical and projected future mean monthly Upper Klamath Lake storage (AF)

5.4.1.2 Keno Dam Inflow

Historical and projected future mean monthly inflow to Keno Dam is summarized in Figure 5-3. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. For the 2030s, the CT scenario indicates slightly higher peak flows while the HW and WW scenarios appear to have the highest increase in peak flow; the HD and WD scenarios show similar or slightly reduced peak flows. By the 2070s managed inflows to Keno Dam also appear to shift toward higher flows earlier in the year. Results indicate mean annual volumes increase under the wetter scenarios (HW and WW). Overall increases in Keno Dam

> **Mean Monthly Flow**
>
> Projections indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

inflow are primarily driven by increases in inflows to Upper Klamath Lake and thereby increases in Link River Dam outflows.

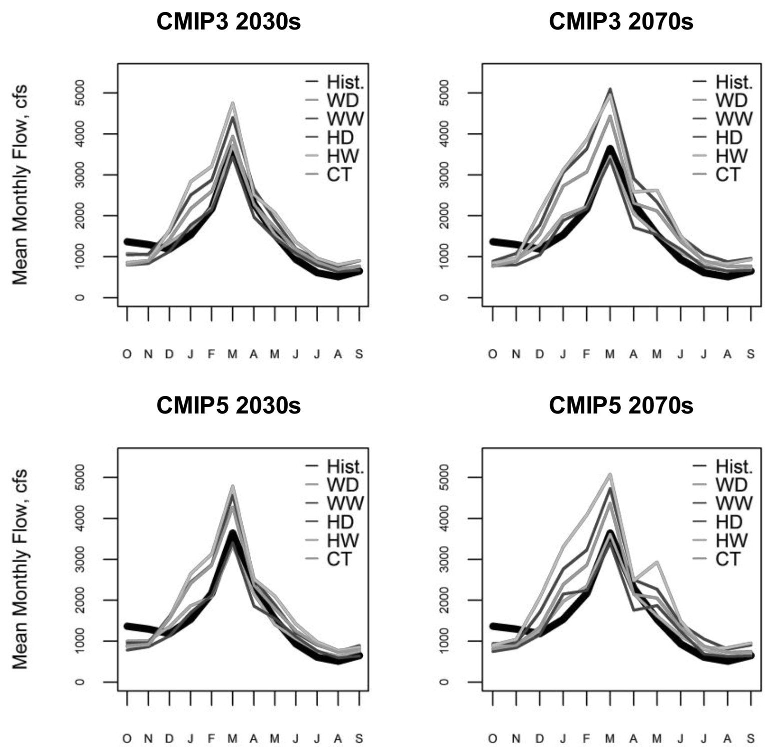


Figure 5-3. Historical and projected future mean monthly managed inflows to Keno Dam (cfs)

5.4.1.3 Iron Gate Reservoir Storage

Historical and projected future mean monthly Iron Gate Reservoir storage is summarized in Figure 5-4. Historically, EOM reservoir storage would peak in March and have its lowest storage in the summer months. Reservoir storage historically did not fluctuate substantially through the year, generally varying between about 55,000 acre-feet and almost 57,000 acre-feet. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase; none of the climate change scenarios indicate a reduction in peak reservoir storage.

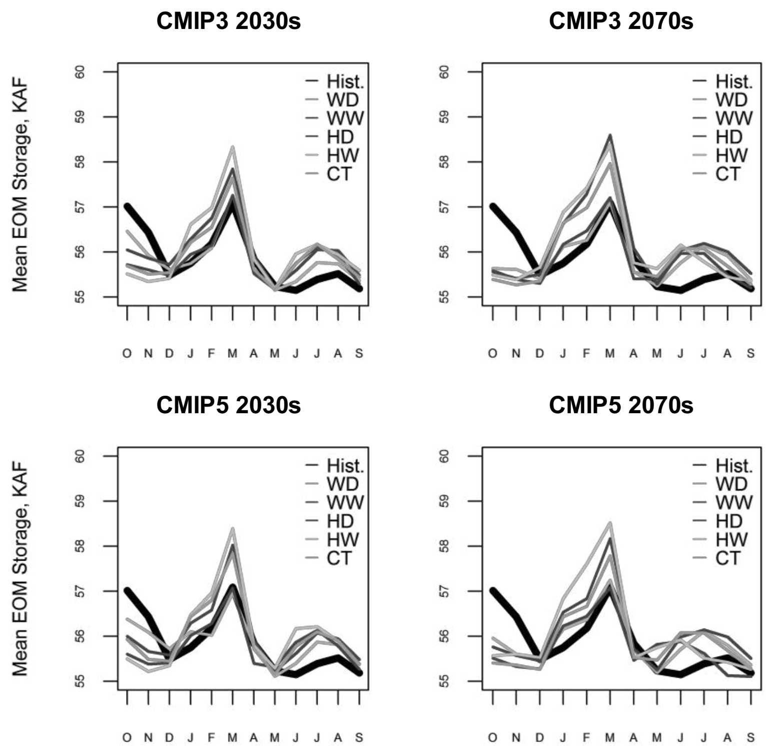


Figure 5-4. Historical and projected future mean monthly Iron Gate Reservoir storage (KAF)

5.4.1.4 Iron Gate Reservoir Outflow

Historical and projected future mean monthly outflow from Iron Gate Dam is summarized in Figure 5-5. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. Historical and projected changes in outflow at Iron Gate Dam correspond with those found at Keno, primarily due to their conjunctive management under the 2013 Proposed Action for Klamath Project operations. Projected changes in peak outflow are similar to Keno inflow in that the WW and the HW scenarios suggest the greatest increases. Also, particularly for the 2070s, substantial increases in flow during the months of January and February are projected. Differences between mean monthly inflows at Keno and outflow at Iron Gate from about May through September, namely projected increases at Keno and projected decreases at Iron Gate, are due to a combination of operating criteria and hydrology. Local inflows between Keno and Iron Gate are projected to decrease, which may contribute to the differences

during this period. Also during these months environmental flow requirements often govern operations, and these requirements are generally accounted for at Iron Gate Dam to maintain minimum flows. These operating criteria may result in differences in projected flows at the two locations.

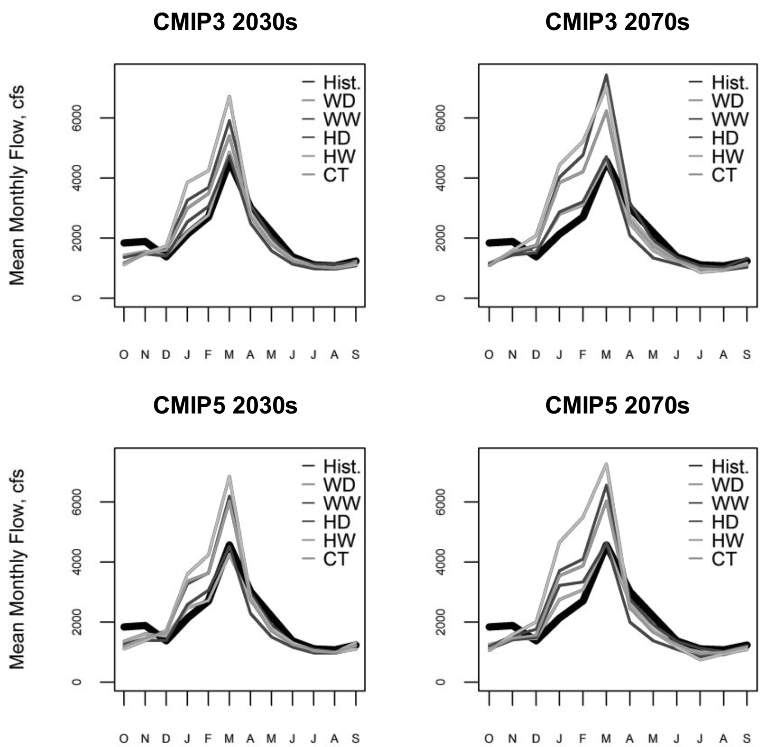


Figure 5-5. Historical and projected future mean monthly Iron Gate Reservoir outflow (cfs)

5.4.1.5 Shasta River Flow

Historical and projected future mean monthly flows in the Shasta River near Yreka are presented in Figure 5-6. Historical mean monthly flows exhibit a double peak, in January and again in March, the first corresponding with the period of seasonal peak rainfall and the second corresponding with snowmelt. The lowest flows occur during August. Projections of climate change indicate a range of increased snowmelt runoff contributing to streamflow (HW and WW scenarios) to decreased snowmelt runoff for the drier scenarios (HD and WD), with the central tendency similar or slightly less than historical. Flows during the

rainfall peak period are projected to increase for all but the WD scenario for the 2030s time period. By the 2070s, all scenarios project increased rainfall-driven peak flow in January. In addition, all but the WW scenario indicate reduced late spring flows, likely due to decreased snowpack (except for Mount Shasta, which is projected to experience increased snowpack due to increased precipitation and high elevations).

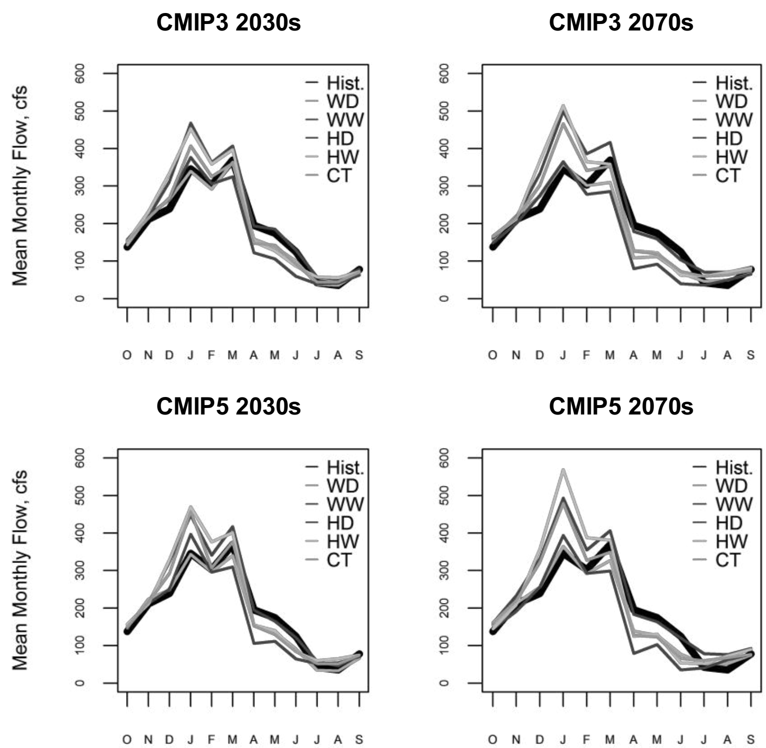


Figure 5-6. Historical and projected future mean monthly flow in the Shasta River near Yreka (cfs)

5.4.1.6 Scott River Flow

Historical and projected future mean monthly flows in the Scott River near Fort Jones are presented in Figure 5-7. The Scott River is a more rain-dominated watershed than the neighboring Shasta River watershed to the east. Historical mean monthly flows reflect a mixture of rain and snow during winter and early spring months, with seasonal peak flows occurring in March but closely followed by January and February. Climate change projections for both the 2030s and 2070s time periods, for both CMIP3 and CMIP5 based projections, indicate increased winter flows as a result of corresponding projected increases in precipitation. Also, the snowmelt runoff contribution to flow in the late spring months is projected to decrease.

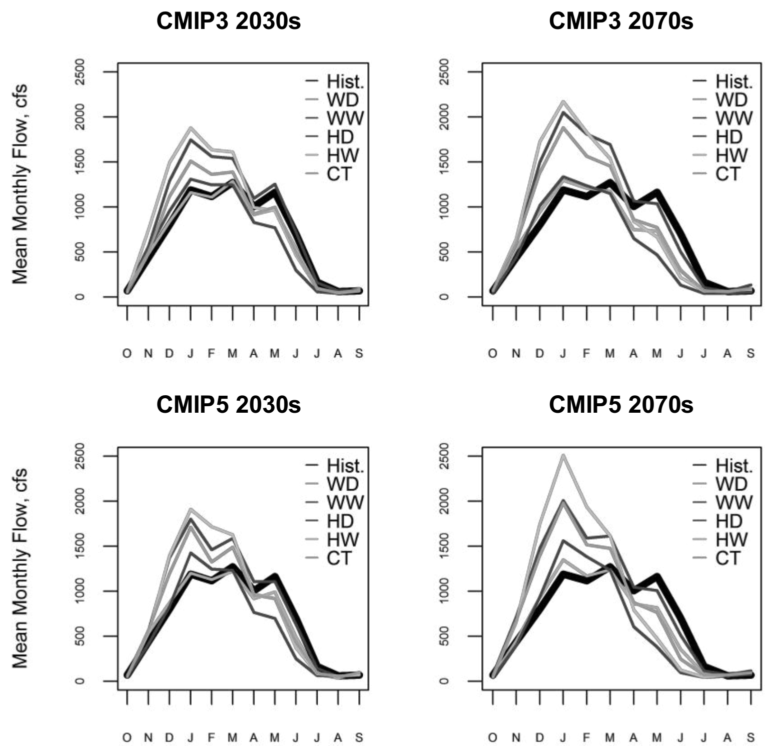


Figure 5-7. Historical and projected future mean monthly flow in the Scott River near Fort Jones (cfs)

5.4.1.7 Flow at Klamath River near Orleans

Historical and projected future mean monthly flows in the Klamath River near Orleans are presented in Figure 5-8. Managed flow in the Klamath River at Orleans reflects Upper Klamath Basin management and the contribution of tributary flows upstream of the Trinity River confluence. Historical mean monthly flows have a primary peak in March as a result of snowmelt runoff and a secondary peak in January as a result of winter rainfall. Projections of future conditions indicate increased peak flows for all scenarios, with the driest scenarios (HD and WD) similar in magnitude to historical. For the 2070s, a projected shift in the peak flow to earlier in the year corresponds with the reduced influence of snowmelt runoff as the climate warms and snowpack declines.

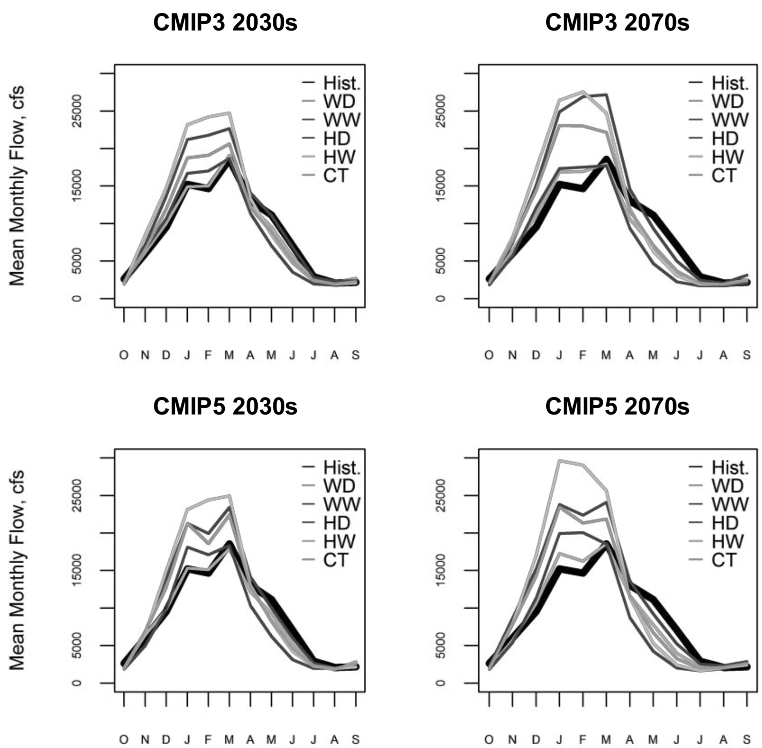


Figure 5-8. Historical and projected future mean monthly flow in the Klamath River near Orleans (cfs)

5.4.1.8 Flow at Klamath River near Klamath

Historical and projected future mean monthly flows in the Klamath River near Klamath are presented in Figure 5-9. Simulated flows in the Klamath River at Klamath integrate managed flows in all of the Klamath River Basin, including contributions from the Trinity River which are affected by Central Valley Project exports to the Sacramento River Basin. Historical mean monthly flows at this location exhibit a double peak in January and March corresponding with rainfall and snowmelt runoff, respectively. Projected changes in mean monthly flows for all but the driest climate change scenarios for the 2030s indicate a shift toward a more rain dominated basin, with peak flows occurring January. Interestingly, projected mean monthly flows at Orleans (Figure 5-8) do not show the same shift, corresponding with a greater increase in January flows in the Trinity River, whose confluence with the mainstem Klamath River is located between Orleans and Klamath. This may be due to the methods used to develop Trinity River flows; Trinity and Lewiston reservoirs were not explicitly modeled and instead adjusted outflows were used as input to RiverWare based on relationships between simulated natural flows (developed in Chapter 3) and historical gage records.

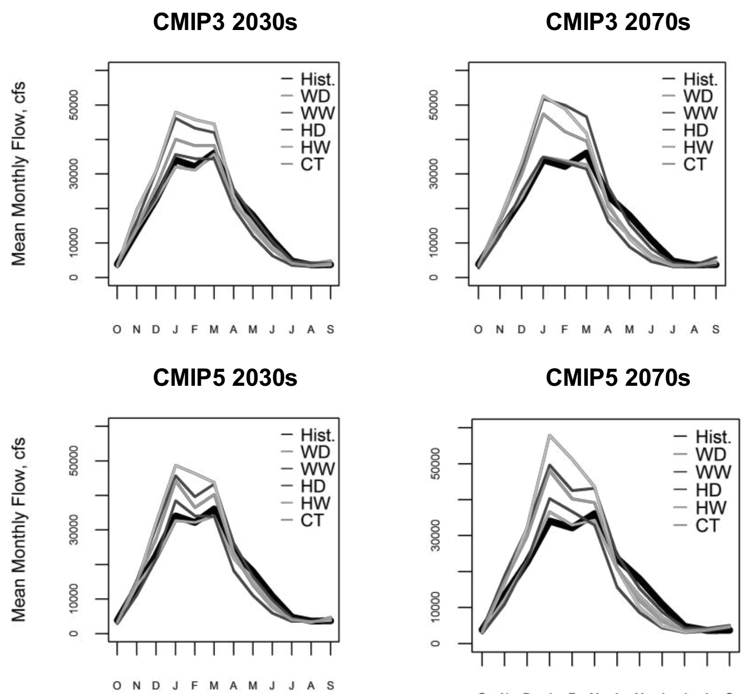


Figure 5-9. Historical and projected future mean monthly flow in the Klamath River near Klamath (cfs)

5.4.1.9 Klamath River Water Temperature

Historical and projected future mean monthly temperatures in the Klamath River near Klamath, as simulated by the RBM10 model, are presented in Figure 5-10. Historical water temperatures are at their maximum in August and at their minimum in January. Water temperature is projected to increase under all climate change scenarios considered by the study for both CMIP3- and CMIP5-based projections, and for both future time periods. Water temperatures historically are not favorable for salmon and projected increases in temperature exacerbate this issue.

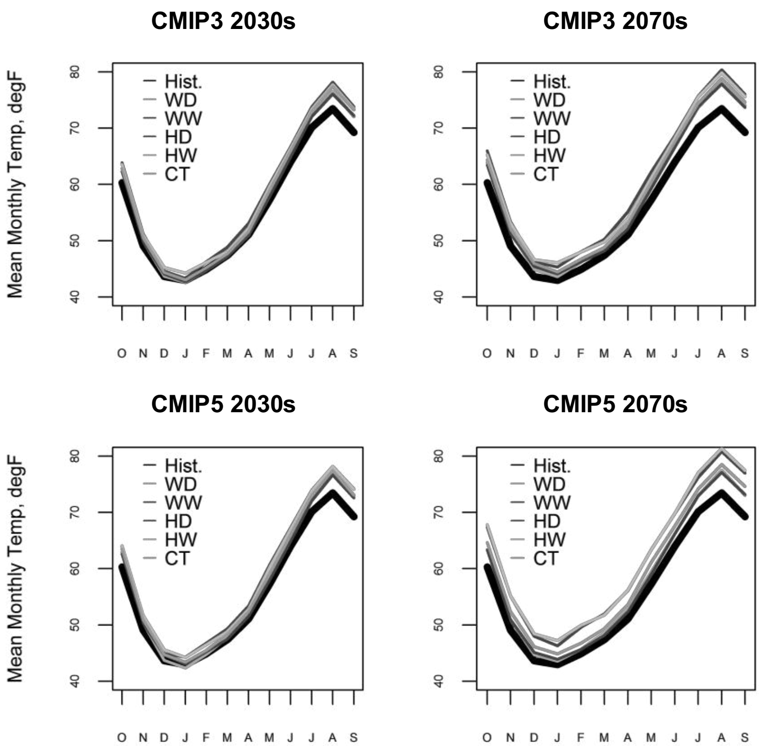


Figure 5-10. Historical and projected future mean monthly water temperature in the Klamath River (degrees F)

5.4.2 Analysis of Impacts – Ability to Deliver Water

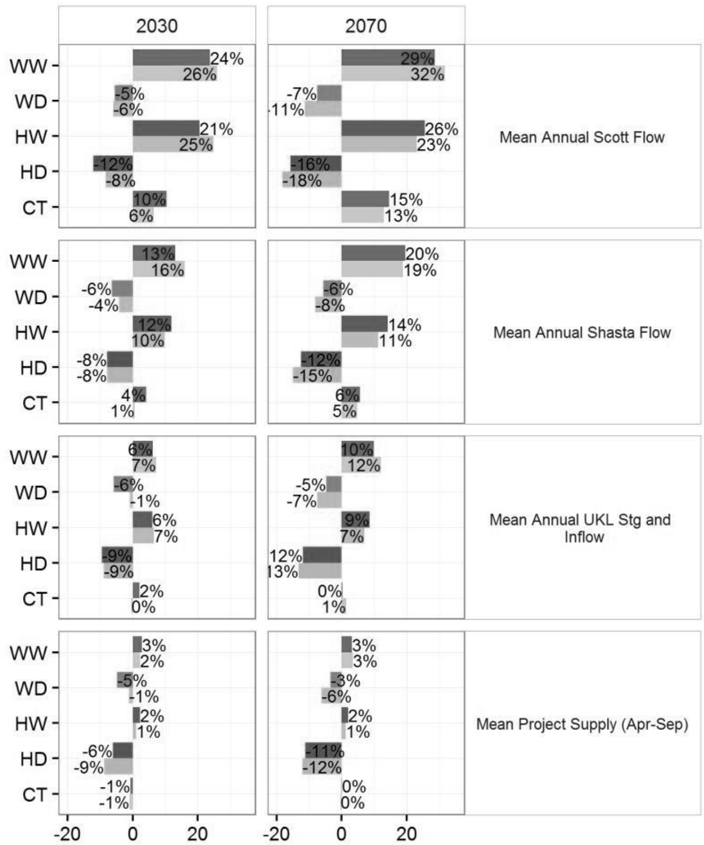
To evaluate the ability of the Klamath River Basin to supply water to meet human needs, this study focuses on four measures: the percent of full irrigation water supply to the Klamath Project (from April through September), the mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow, mean annual flows in the Shasta River near Yreka, and mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Water supply measures under simulated historical conditions are provided in Table 5-6, while projected changes in these measures are illustrated in Figure 5-11. Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the simulation period, the sum of end-of February storage plus March–September inflows at Upper Klamath Lake (another indicator of total available supply from Upper Klamath Lake) was about 1.38 million acre-feet. Additional measures representing the total water supplies in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

> **Projected Klamath Project Supply**
>
> Klamath Project irrigation deliveries average about 93 percent of full supply under historical hydrology according to simulations by the Klamath Basin RiverWare Model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Table 5-6. Historical measures related to water supply.

Measure	Historical Value	Units
Mean Klamath Project supply	361.3	KAF
Mean annual UKL seasonal supply	1,378	KAF
Mean annual Shasta flow	187.7	cfs
Mean annual Scott flow	668.8	cfs



Notes: Changes are represented as percentages; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-11. Projected changes in water supply measures

In terms of the projected changes in water supply measures shown in Figure 5-11, projected changes in mean annual flow in the Scott and Shasta Rivers include increases for the wetter scenarios (WW and HW) close to about 20 percent for the 2030s and 30 percent for the 2070s and decreases for the drier scenarios (WD and HD) of less than 10 percent for the 2030s and 10 to 20 percent for the 2070s, with a central tendency scenario showing more modest increases than the wetter scenarios. For mean Upper Klamath Lake supply (end-of-February storage plus March-September inflow), again the wetter scenarios indicate projected increases, with greater increases for the 2070s, while drier scenarios indicate decreases. Similar results are shown for mean Klamath Project supply from April through

September. Percent change in Upper Klamath Lake supply and Klamath Project supply (the bottom two measures listed in Figure 5-11) is computed based on projected and historical simulated values under the 2013 BiOp management criteria. No consistent differences are apparent in comparing CMIP3- and CMIP5-based scenarios. However, together they provide comprehensive information on the projected range of changes in these water delivery measures. Table 5-6 summarizes the data behind Figure 5-11.

5.4.3 Analysis of Impacts – Hydroelectric Power

To evaluate historical conditions and impacts of climate change on hydroelectric power production, the study focuses on the following measures: mean annual hydropower production (summed over J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities); mean annual spill volumes at J.C. Boyle, COPCO 1, and Iron Gate dams; and mean spill days per year at the same three dams. Measures are computed using results from the Klamath Basin RiverWare model.

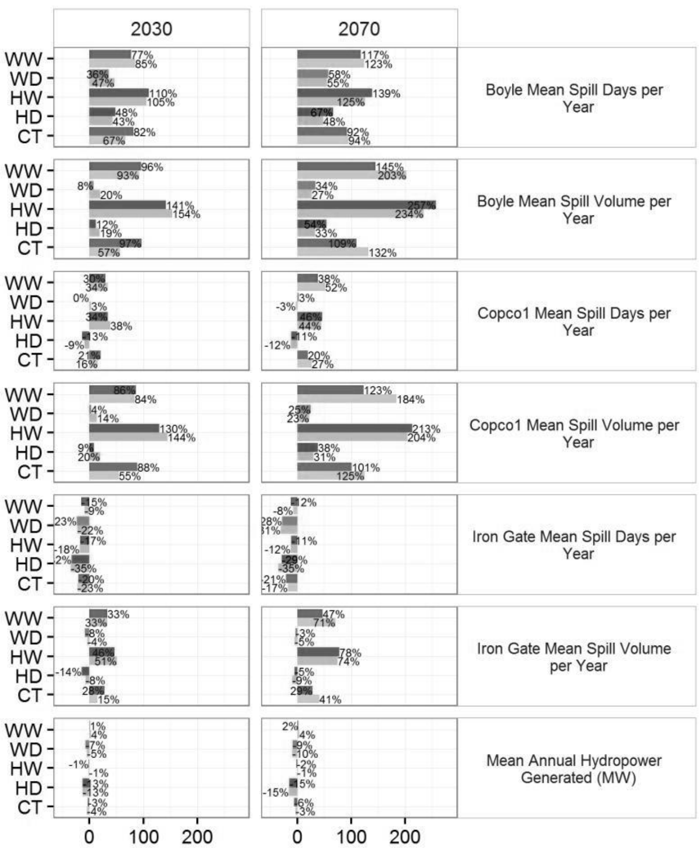
Historical hydropower measures are provided in Table 5-7, while projected changes in these measures are illustrated in Figure 5-12. Note that mean annual days with spill at the three facilities over the historical simulation period are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate.

Projected Hydropower Production

Hydropower production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. For all facilities, under almost all scenarios, frequency and volume of spill is likely to increase.

Table 5-7. Historical measures related to hydroelectric power

Measure	Historical Value	Units
Mean annual hydropower generated (MW)	26,741	MW
J.C. Boyle mean spill volume per year	163.0	KAF
COPCO 1 mean spill volume per year	186.4	KAF
Iron Gate mean spill volume per year	533.9	KAF
J.C. Boyle mean spill days per year	105.9	days
COPCO 1 mean spill days per year	42.8	days
Iron Gate mean spill days per year	170.3	days



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-12. Projected changes in hydropower measures

Figure 5-12 illustrates the percent change in identified hydroelectric power measures. Consistent with results discussed for basin-wide response variables, namely increased seasonal peak flows, the number of spill days and the mean annual spill volumes are projected to increase for most scenarios for both future time horizons. However, at Iron Gate the projected changes in spill volume are generally increasing, while the projected change in the mean number of spill days per year is less substantially decreasing. Projected mean number of spill days at J.C. Boyle and COPCO1 are generally increasing, while generally decreasing at Iron Gate. This result may be due to the fact that Iron Gate Reservoir has greater storage and is therefore better able to absorb high inflows than J.C. Boyle or

COPCO1. Also, the management criteria allow inclusion of a rule to avoid spill at Iron Gate, but not at J.C. Boyle or COPCO1, due in part to the need to meet environmental flow requirements.

Also, projected changes in mean annual hydropower production are much smaller on a percentage basis than the other measures, with the wetter scenarios indicating increases, the drier scenarios indicating decreases, and the central tendency scenario indicating minimal increases. Changes are between +4 percent and -13 percent for the 2030s and between +4 percent and -15 percent for the 2070s. Appendix D, Table D-12 summarizes the data behind Figure 5-12.

5.4.4 Analysis of Impacts – Recreation

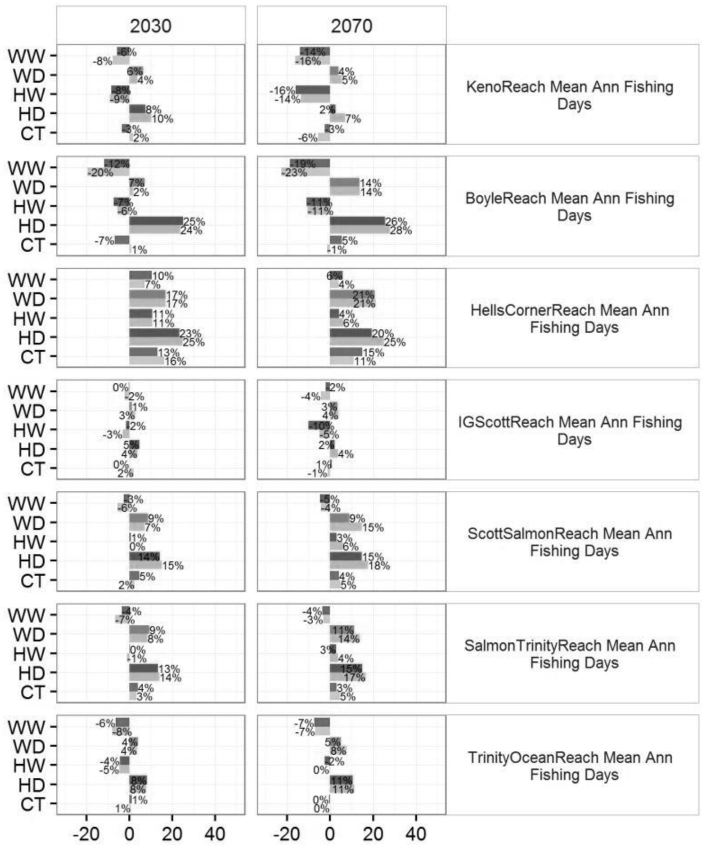
Recreational measures in the Klamath River Basin are summarized for two main categories, fishing recreation and river boating recreation. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in select Klamath River reaches fall within the recommended range for each activity. Measures are computed using results from the Klamath Basin RiverWare model.

Table 5-8 provides historical recreation measures for fishing and river boating, while projected changes in these measures are illustrated in Figure 5-13 (for fishing) and Figure 5-14 (for river boating). For the historical period, in general more days fall within the recommended range for fishing than for river boating.

> **Recreation**
>
> The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Table 5-8. Historical measures related to fishing recreation

Measure	Historical Value	Units
Keno Reach mean annual fishing days	248	days
Boyle Reach mean annual fishing days	155	days
Hells Corner Reach mean annual fishing days	220	days
IG Scott Reach mean annual fishing days	275	days
Scott Salmon Reach mean annual fishing days	184	days
Salmon Trinity Reach mean annual fishing days	214	days
Trinity Ocean Reach mean annual fishing days	253	days
Keno Reach mean annual boating days	172	days
Boyle Reach mean annual boating days	59	days
Hells Corner Reach mean annual boating days	256	days
IG Scott Reach mean annual boating days	275	days
Scott Salmon Reach mean annual boating days	249	days
Salmon Trinity Reach mean annual boating days	214	days
Trinity Ocean Reach mean annual boating days	253	days



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-13. Projected changes in fishing recreation

For fishing recreation, the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios (WW and HW) indicate decreases in the number of fishing days for both future time horizons. Recommended flows for fishing are generally less than for boating, and overall projections of greater future flow volumes in the basin correspond with projected decreases in fishing days. The central tendency scenario indicates modest decreases in some reaches and modest increases in other reaches. Generally, the direction of change (increase or decrease) is consistent for both future time horizons within a given reach (except J.C. Boyle reach and Trinity Ocean reach). For some scenarios and measures, CMIP3-based projections indicate greater

change, while for others they may indicate smaller change. There is no consistency between CMIP3- and CMIP5-based projections in terms of projected change across scenarios or measures.

Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-14. Projected changes in river boating recreation measures

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. For instance, in the J.C. Boyle and Hells Corner reaches (from J.C. Boyle to COPCO 1) almost all scenarios indicate a decrease in the number of river boating days as a result of climate change, with the exception of the WW scenario for CMIP3 and the CT scenario for CMIP5. For the other reaches downstream of Iron Gate, the wetter

scenarios (WW and HW) generally indicate a reduction in the number of river boating days, while the drier scenarios (WD and HD) indicate increases in the number of river boating days (although not consistent for all measures). The CT scenario for those reaches below Iron Gate indicates modest changes (increases for most of those reaches). Note that the boating recreation measures do not account for the ability to release flows from J.C. Boyle to assure a suitable boating recreation flow range.

5.4.5 Analysis of Impacts – Ecological Resources

Measures related to ecological resources in the Klamath River Basin primarily concern fish and wildlife habitat and applicable species listed under ESA. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in the Scott and Shasta Rivers meet or exceed recommended flow thresholds for dry year conditions by McBain and Trush (2014). Note that the target flows were developed for the Shasta River and the same targets were applied to the Scott River, though the Scott River generally has greater flow volume. For this reason, the historical frequency of meeting flow targets in the Scott River is much higher than in the Shasta River. However, the dry year targets are not met 100 percent of the time in the Scott River.

Historical conditions and climate change impacts are also measured by computing watersupply to the Lower Klamath National Wildlife Refuge via Ady Canal. Measures are computed using results from the Klamath Basin RiverWare model.

> **Ecological Resources Impacts**
>
> The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. Also, a decrease in deliveries to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

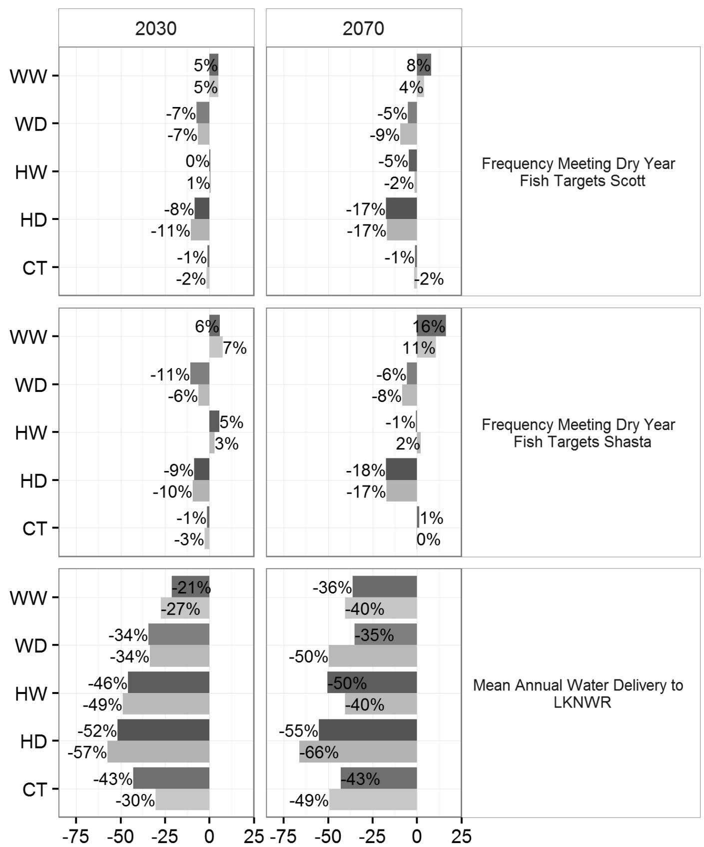
Historical measures relating to ecological benefits are provided in Table 5-9, while projected changes in these measures are illustrated in Figure 5-15. For the historical simulation period, neither dry year flow targets nor full demand at the LKNWR are met 100 percent of the time.

Table 5-9. Historical measures related to ecological resources

Measure	Historical Value	Units
Frequency meeting dry year fish targets Scott	70.5	Percent of days
Frequency meeting dry year fish targets Shasta	56.9	Percent of days
Mean annual water delivery to LKNWR	24.6	KAF

Projected changes in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers, represented as a percentage, indicate increases for

the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and HD), with greater change projected for the 2070s time horizon compared with the 2030s. CMIP3- and CMIP5-based projections are comparable, with one set of scenarios generally exhibiting more change (although not consistently one over the other). The CT scenario indicates a modest decrease in the frequency of ability to meet the dry year flow targets (i.e., negative change).



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-15. Projected changes in ecological resources measures

Figure 5-15, illustrating the percent change in the mean annual (water year) supply to the LKNWR, shows that for all climate change scenarios there is a decrease in supply to the LKNWR, more so for the 2070s compared with the

2030s future time horizon. CMIP3- and CMIP5-based scenarios are comparable, but do show some differences. For the 2030s CT scenario, the CMIP5-based scenario indicates a reduction of about 43 percent, compared to 30 percent for the CMIP3-based CT scenario. Note that model results indicate a decrease in deliveries to LKNWR for all scenarios, while they indicate projected increases or decreases in Klamath Project supply depending on the scenario. These results may in part be explained by a projected reduction in water supply from the Lost River. Also note that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Additionally, the LKNWR is not able to take advantage of spill water under these management criteria. The resulting effect of the management criteria and projected hydrologic changes is an overall reduction in LKNWR deliveries.

Frequency of meeting minimum recommended pool elevations in Clear Lake and Gerber Reservoir were also computed as performance measures for evaluating climate change impacts. These results are not illustrated, as minimum pool elevations are met or exceeded in all climate change scenarios considered by the Basin Study. Note that climate change scenarios represent adjusted historical climates that represent the statistics of future climate for two future time horizons, the 2030s and 2070s. Therefore, potential changes in the timing and frequency of drier years and wetter years are not represented. Potential future changes in drought or wet period frequency may affect the ability of operators to maintain minimum pool elevations in Gerber Reservoir and Clear Lake.

Water Quality Impacts

For historical hydrology conditions and all future climate scenarios, the MWAT falls within the “poor” classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

5.4.6 Analysis of Impacts – Water Quality

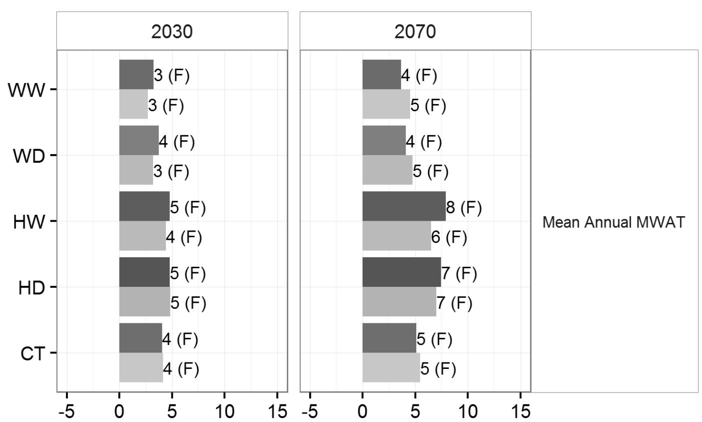
Water quality measures are presented in terms of meeting Klamath River temperature thresholds in the Klamath River near Klamath, California as recommended by the SONCC ESU salmon recovery plan (NMFS, 2012). Historical conditions and climate change impacts are evaluated by computing the mean across the simulation period of the MWAT at the Klamath River near Klamath and comparing values with those recommended in the salmon recovery plan. Analysis under historical hydrology showed that the MWAT fell within the “poor” classification for all years. Therefore, instead of reporting the frequency of the MWAT falling within the various categories ranging from “very good” to “poor,” we instead report the computed MWAT and projected change in that value, as well as the degrees F by which the “poor” classification is exceeded. The “poor” classification threshold is 63.68 degrees F, or 17.6 degrees C.

Historical measures relating to water quality are provided in Table 5-10, while projected changes in these measures are illustrated in Figure 5-16. Historically the MWAT is computed as 75.7 degrees F, which is approximately 12 degrees higher than the "poor" classification threshold for the SONCC ESU coho salmon.

Table 5-10. Historical measures related to water quality.

Measure	Historical Value	Units
Mean annual MWAT	75.7	degrees F
Mean exceedance of MWAT – Poor	12.1	degrees F

Figure 5-16 shows that for all climate change scenarios the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s. Results indicate that the temperature regime in the Klamath River is likely to become more challenging for coho salmon under warmer future climate scenarios. Identified cold water refugia and groundwater springs will continue to be critical for the survival of the species in the Klamath River Basin.



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-16. Projected changes in mean annual maximum weekly average temperature

5.4.7 Analysis of Impacts – Flood Control

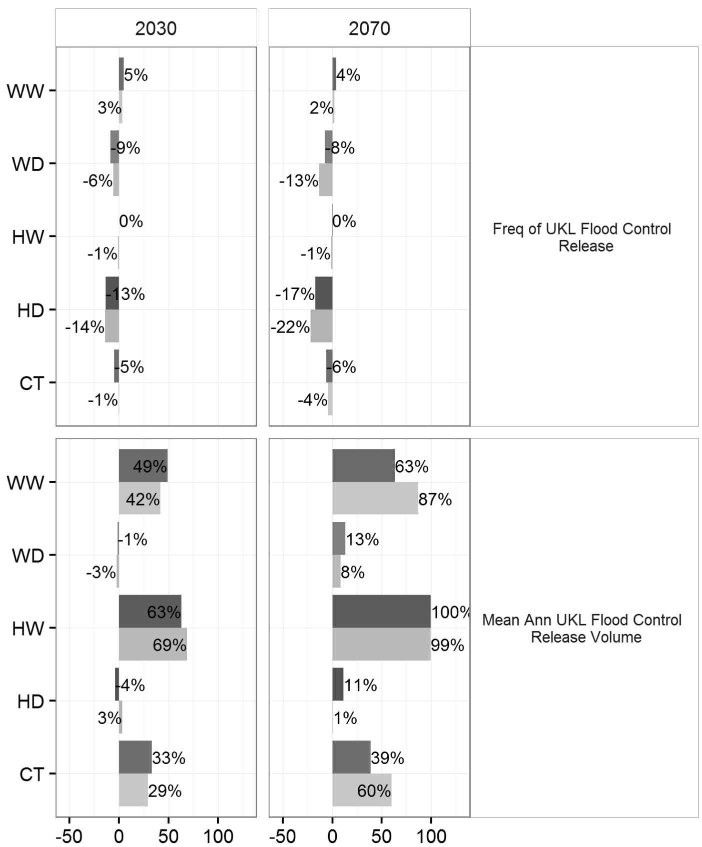
Flood control in the Klamath River Basin and projected changes due to a changing climate are evaluated for two types of measures: flood control releases from Upper Klamath Lake, and the date of seasonal peak flow at the major mainstem Klamath River dams (J.C. Boyle, COPCO 1, and Iron Gate). Flood control rules at Upper Klamath Lake are defined by the 2013 Proposed Action for Klamath Project Operations (Reclamation, 2012d). It is recognized that flood control measures exist for other reservoirs in the Klamath River Basin (e.g., Trinity River basin); however, due to the level of detail of the Klamath Basin RiverWare model, we focus on Upper Klamath Lake.

> **Flood Control Impacts**
>
> The frequency of Upper Klamath Lake flood control releases is projected to increase for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest increase. All scenarios project an increase in the mean annual flood control volume.

Historical recreation measures relating to flood control are provided in Table 5-11, while projected changes in these measures are illustrated in Figure 5-17. Under historical hydrology conditions, the frequency of flood control releases from Upper Klamath Lake is approximately 44 percent of days according to results from the Klamath Basin RiverWare model. The corresponding mean annual volume of flood control release water is approximately 224,000 acre-feet. Flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. The computations are consistent between the RiverWare model and the KBPM. However, it is acknowledged that the RiverWare model simulations generally indicate greater flows coming from the Lost River basin, thereby resulting in less demand by the Klamath Project for Upper Klamath Lake water, compared with the KBPM. This result may contribute to the seemingly high percentage of days of flood control release from Upper Klamath Lake. Greater flows from the Lost River basin may also explain some of the higher Keno Dam inflows in the winter time (refer to Figure 5-3). Future development of the model will further investigate these issues. The date of seasonal peak flow is the date of the center of mass of mean annual flow, or the average date by which half of the annual flow volume at the location has passed through. The historical seasonal peak flow at the three reservoirs mentioned ranges from early to mid-April.

Table 5-11. Historical measures related to flood control

Measure	Historical Value	Units
Frequency of UKL Flood Control Release	44.1	Percent of Days
Mean Ann UKL Flood Control Release Volume	224	KAF
Date of Seasonal Peak Flow at J.C. Boyle Reservoir	April 9	Date
Date of Seasonal Peak Flow at COPCO 1 Reservoir	April 17	Date
Date of Seasonal Peak Flow at Iron Gate Reservoir	April 15	Date



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-17. Projected changes in flood control measures

Figure 5-17 shows that the frequency of Upper Klamath Lake flood control releases is projected to increase or change minimally for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. Again, CMIP3- and CMIP5-based projections are generally consistent. Although there is a projected decrease in the frequency of flood control releases for several scenarios, the figure also shows that all scenarios show a projected increase in the mean annual flood control volume. Further, more water is being released in the future even though the occurrence of release may be decreasing. Minimal projected change in Upper Klamath Lake flood control release, along with projected increases in spill volumes at J.C. Boyle and COPCO1 (refer to Figure 5-12), may be explained by the different ways spill is accounted for at these locations. At Upper Klamath Lake, spill is considered the volume beyond that released for Klamath Project deliveries and environmental needs, whereas at the other locations it is more simply computed as the volume above which water can be released through the power facilities. Management criteria also play a role in the differing results.

The projected change in the date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate dams ranges from little or no change to a shift toward an earlier peak by as many as 17 days (HW scenarios for CMIP3 and CMIP5 for the 2070s future time horizon). For the 2030s, the CT scenario indicates a shift toward earlier in the year by up to one week at COPCO 1 and Iron Gate, while for the 2070s the projected change for the CT scenario is about 7 to 10 days earlier. In general, projected changes in the date of seasonal peak flow at J.C. Boyle are less substantial than at the other two locations evaluated, with projected changes having ranging from 1 to 4 days later for the 2030s, and 4 days earlier to 3 days later for the 2070s depending on the scenario. Table D-13 in Appendix D summarizes the results for all scenarios and time periods.

5.5 Summary of Findings

This chapter evaluates the ability of the basin to meet historical and projected future water needs using a framework of models and associated measures that are used to quantify vulnerabilities. Simulations (with historical and future hydrology conditions) were performed using existing operational constraints, mainly associated with the current Proposed Action for Klamath Project operations (Reclamation, 2012d), which dictate operations throughout the Upper Klamath Basin and have implications for the river from Link River Dam to its mouth.

Performance measures for selected categories provide a basis for assessing two things: first, the ability of the modeling framework to identify and evaluate vulnerabilities to meeting the basin's water needs, and second, the ability to evaluate the impacts of climate change on the watershed. The results provide useful insights as to how climate changes, without adaptation responses, impact the Klamath Basin. The following paragraphs summarize the above analysis of managed historical and projected future conditions.

Analysis of climate change impacts using the Klamath Basin RiverWare model and USGS RBM10 water temperature model show that mean EOM storage in Upper Klamath Lake will experience earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, EOM reservoir storage historically did not fluctuate substantially through the year. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase slightly. Projections of mean monthly managed flows at various locations throughout the study area indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

Figure 5-2 showing simulated historical and projected UKL storage helps to illustrate the projected change. The simulations show historical peak storage around May. Projections indicate a shift toward earlier peak storage. In addition, the simulations indicate more flood control release (any release above Project needs and environmental requirements) in the future as well. Although none of the figures illustrate UKL inflow, it appears that Project supply is projected to decrease slightly for the drier scenarios and increase slightly for the wetter scenarios, with a small increase for the central tendency scenario. Therefore, any reduction in summer UKL inflow does not appear to affect Project supply by a large amount, on average.

Historical hydrology enables an annual average of 93 percent of full delivery to Klamath Project irrigation, according to simulations by the Klamath Basin RiverWare model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Hydropower production summed for the J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities has historically been about 26,800 MW, according to RiverWare model simulations. Production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. We evaluated frequency and volume of spill at J.C. Boyle, COPCO 1, and Iron Gate dams and found that historically the dams spilled an average of 106 days at J.C. Boyle, 43 days at COPCO 1, and 170 days at Iron Gate per year. For all facilities, frequency and volume of spill is likely to increase with climate change.

Historical fishing and boating recreation in the Klamath River Basin has been strong (on the order of 155 to 275 fishing days per year and 59 to 275 river boating days per year). The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Using flow recommendations for a dry year in the Shasta River (defined as 61 to 100 percent exceedance) from McBain and Trush (2014), we found that flow

targets were met historically on an average of 57 percent of days in the Shasta River and 71 percent of days in the Scott River (which has about three times the mean annual flow of the Shasta River). The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. In the future, a decrease in water delivery to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

For historical conditions and all future scenarios, the MWAT falls within the "poor" classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

Finally, according to the Klamath Basin RiverWare model, the historical frequency of flood control releases from Upper Klamath Lake has been about 44 percent of days, with a mean volume of about 224,000 acre-feet. The frequency of these releases is projected to increase or show little change for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. All scenarios project an increase in the mean annual flood control volume. The date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate has historically been early to mid-July, according to the model simulations. Projections of future conditions show a general shift of this peak toward earlier in the year, although the degree to which this is the case varies by scenario and location. The most modest changes are projected for J.C. Boyle (on the order of 4 days later to 3 days earlier for the 2070s). Greater shifts are projected for COPCO 1 and Iron Gate, on the order of 1 day later to 9 days earlier for the 2030s and 2 to 16 days earlier for the 2070s.

Results of the system risk and reliability analysis support the common understanding that the Klamath River Basin has experienced difficulties in meeting the range of water needs. Projected increases in precipitation and flow volumes at many locations in the basin may reduce water supply gaps in some ways; however, greater challenges are projected for ecological resources such as fish and wildlife, as well as irrigators in the Upper Klamath Basin.

5.6 Uncertainties Associated with System Reliability Analysis

This section summarizes uncertainties associated with various aspects of the Klamath River Basin Study system risk and reliability analysis. The uncertainties primarily correspond to the modeling used to evaluate historical and future conditions. The modeling framework for this analysis includes development and implementation of the Klamath Basin RiverWare model, as well as implementation of the USGS RBM10 water temperature model for the mainstem Klamath River. Uncertainties associated with each of these modeling efforts are

identified and described below. Further discussion of uncertainties associated with the Klamath Basin RiverWare model will be presented as part of a separate technical report documenting the development of the model.

The Klamath Basin RiverWare model was developed as a basin-wide tool for simulating current operations under the 2012 Proposed Action for Klamath Project operations (Reclamation, 2012d). Operating rules for the Proposed Action were translated from the original modeling platform of the Klamath Basin Planning Model into RiverWare. Because the KBPM modeling platform differs from the RiverWare platform, management rules in some instances were modified to accommodate the RiverWare platform. Calibration of the RiverWare model, using historical data consistent with KBPM data, was performed to the best of our ability. However, differences persist between historical hydrology-driven model simulations using the KBPM and the RiverWare models. Model calibration will continue to be addressed in the future as the model is applied to future projects.

The USGS RBM10 water temperature model was used in its original form as part of the Basin Study. Historical inputs consistent with the Basin Study water supply and demand assessments were used as input to the RBM10 model to maintain consistency within the Basin Study. Many of these inputs differed from those used in the original implementation of the RBM10 model for the dam removal studies. As such, we employed a bias correction technique for the meteorological data so it better represented the statistics of the original model data. This also facilitated use of the model in the Basin Study because, under this methodology, it was not necessary to recalibrate parameters of the water temperature model.

Simulated managed streamflows at boundary locations used by the RBM10 model were provided by the Klamath Basin RiverWare model. Original development of the RBM10 model used USGS gage data for these boundary inputs. Historical simulated RiverWare model output was, as expected, different from the inputs for the original model. Within the RiverWare model, it was possible to experience negative or close to negative flows in certain river reaches due to river routing and the computation of reach gains. The RBM10 model cannot compute water temperature provided negative river flows, so a 5 cfs adjustment was made to simulated boundary flow for those timesteps where negative flows occurred.

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Chapter 6
Klamath River Basin Study
Evaluation of System Reliability with Strategies

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Chapter 6
Evaluation of System Reliability with Strategies

6.1 Introduction

Chapter 6 presents the process that was developed and utilized to formulate and screen adaptation strategies for reducing identified gaps between water supply and demand. It also identifies the strategies carried forward for quantitative evaluation under the framework developed for the Basin Study, which is further described in Chapter 5, System Risk and Reliability Analysis. Figure 6-1 provides an overall schematic of the Basin Study approach.

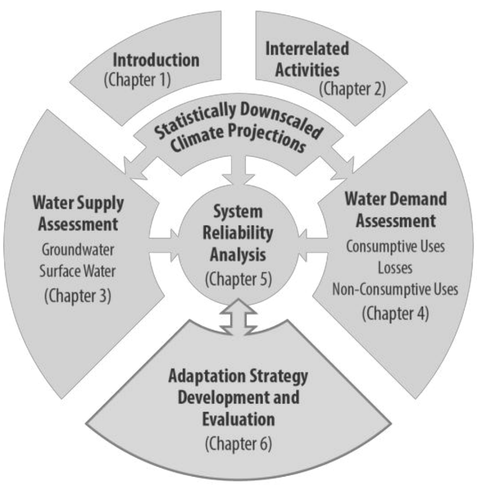


Figure 6-1. Overall approach of Klamath River Basin Study, highlighting Chapter 6

6.2 Formulation of Adaptation Strategies

The overall approach for formulating adaptation strategies to be evaluated in the Klamath River Basin Study includes the following steps:

- Identify strategies that cover a range of options.
- Organize proposed strategies in general categories based on their primary function.
- Characterize strategies based on a set of criteria to facilitate strategy screening.
- Develop representative options that allow for simplified analysis and that avoid redundancy.

Each of these approach steps is further described below.

6.2.1 Approach to Adaptation Strategy Identification

Adaptation strategies were identified through a comprehensive literature review of studies on climate change and water supply issues specific to the Klamath River Basin as well as studies focused on the broader Pacific Northwest. In addition to this literature review, the Basin Study team completed outreach to Klamath River Basin agency representatives, tribal representatives, stakeholders, and residents through conference calls, attendance at water supply management and planning meetings in the basin, and outreach through the Basin Study website.

The literature review effort identified 49 reports, studies, agreements, doctoral dissertations, and masters' theses completed by federal and state resource agencies, tribal natural resource departments, and university researchers. From this literature review and stakeholder input, 185 unique adaptation strategies were identified and carried forward for evaluation in the screening process described below. The full list of identified adaptation strategies is presented in Appendix E.

6.2.1.1 Organization of Proposed Adaptation Strategies

The adaptation strategies were divided into categories to facilitate a comparison of the strategies with similar approaches to addressing water supply and demand changes. These categories – increase supply, decrease demand, modify operations, and governance and implementation – are each populated with multiple strategies. This same general approach was used for the Colorado River Basin Water Supply and Demand Study (Reclamation, 2001e). The four general categories are further described below:

> ***Increase Supply:*** This category encompasses strategies that result in an anticipated increase in water supply or that identify alternative water supplies. Strategy examples include creating groundwater recharge

opportunities, increasing surface storage capacity, increasing the use of recycled water, developing conjunctive use programs, and implementing vegetation management actions.

Decrease Demand: This category encompasses strategies that result in an anticipated decrease in water demand either directly or indirectly. Strategy examples include M&I water conservation (direct reduction), agricultural water conservation (direct reduction), energy water use efficiency (indirect reduction), and reductions in environmental demand (direct reduction).

Modify Operations: This category encompasses strategies that involve alternative management decisions that may result in a change in water supply and/or demand. Strategy examples include improving infrastructure reliability and efficiency, reducing hillslope and/or bank erosion, improving water quality, improving preparedness for extreme events, reducing reservoir and lake evaporation, reducing out of basin transfers, improving intra-regional water transfers, or improving operational flexibility.

Governance and Implementation: This category encompasses strategies that involve changes in policy, management, legal structure, or future governance issues in the Klamath River Basin. Strategy examples include improvements to public education, developing and improving partnerships between stakeholders, improving research, modifying or developing new policies, developing decision support tools, providing for habitat protection, seeking funding, implementing watershed management, and improved land use practices.

Figure 6-2 indicates the number of proposed adaptation strategies identified per category.

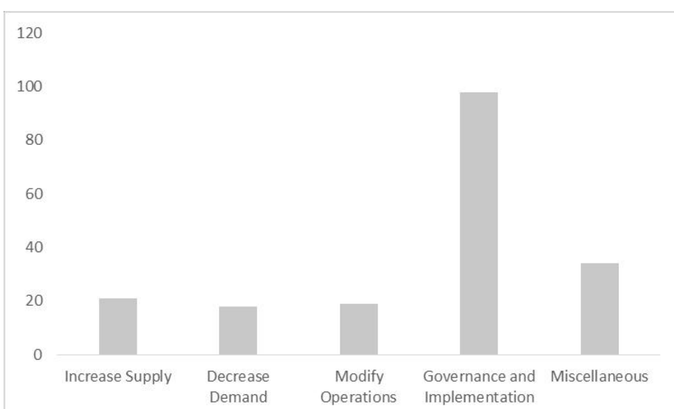


Figure 6-2. Number of adaptation strategies identified

6.2.1.2 Criteria for Adaptation Strategy Screening

Once the proposed strategies were organized into general function categories, they were evaluated and screened in a staged analysis effort. Evaluation measures were utilized to assess each adaptation strategy's capacity to address changes in water supply and demand. These evaluation measures were developed by Reclamation in consultation with the non-federal partners consistent with the selection criteria developed for the evaluation of options during development of the On Project Plan (Klamath Water and Power Agency, 2013). The On Project Plan screening criteria were formulated through an extensive stakeholder outreach process that resulted in wide acceptance of their use for the screening of the water conservation and efficiency, water storage, groundwater development and substitution, and demand management options identified in that planning effort. Reclamation and the non-federal partners relied on these widely accepted criteria during the development of evaluation measures for the Basin Study to incorporate the input already provided by these stakeholders.

The initial screening effort evaluated each strategy in each category to determine if it could be represented by the Basin Study models. Strategies that could be modeled could be quantitatively evaluated in this Basin Study Report; strategies that could not be modeled were evaluated qualitatively. The results of the first screening for each strategy are included in Appendix E.

Following the initial screening, the strategies that could be modeled were evaluated qualitatively, utilizing the criteria detailed below in Table 6-1, to assess the strategy's implementation risk and uncertainty, reliability, and environmental effect. Reclamation and the non-federal partners qualitatively evaluated these screening criteria, arriving at representative strategies that encompass the collective goals of the criteria, present the greatest potential for beneficial effect, and were identified as high priorities to the non-federal partners, while also involving a range of options for reducing identified vulnerabilities in the Klamath River Basin.

Table 6-1. Description of criteria for assessing adaptation strategies

Provides verifiable, durable and implementable benefit to align water supply and demand for the Klamath River Basin
This criterion evaluates whether a strategy is capable of providing verifiable and affordable reductions in projected water supply/demand gaps and assures all associated administrative requirements are reasonable and not overly burdensome or complex. Strategies performing well under this criterion are expected to provide a measurable water supply increase, and strategies with low ratings are anticipated to deliver minimal increases in water supply that would be difficult to verify.
Consistency with legal and regulatory requirements
This criterion evaluates whether a strategy is implementable with respect to compliance with all existing laws, regulations, or contracts, or requires a relatively minor revision in such requirements that would allow for implementation. Strategies that performed well under this criterion had no identified legal and regulatory issues and strategies with low ratings would require major legal or regulatory actions, like new water rights and major environmental compliance investigations.

Table 6-1. Description of criteria for assessing adaptation strategies

Affordability
This criterion evaluates whether a strategy furthers the objective of aligning demand with Klamath water supply availability in a manner that is commensurate with the cost, allowing for a comparison of the relative cost of alternative strategies. This criterion was rated with high ranking strategies requiring no new costs or investment and low performing strategies requiring large capital expenditures and/or high long-term operations and maintenance costs.
Flexibility
This criterion evaluates whether a strategy would have, or not unduly limit, the capability to be adjustable over time. This criterion was rated with high ranking strategies allowing for implementation to be adjusted over time and low ranking strategies implementing new infrastructure that could not be moved or have its operations modified.
Protection of water rights
This criterion evaluates whether a strategy would result in injury to existing water rights holders. This criterion was rated with high ranking strategies producing no effect on existing water rights and low ranking strategies potentially impacting neighboring surface and groundwater availability.
Environmental and third-party impacts and benefits
This criterion evaluates whether a strategy would comply with applicable environmental laws and not involve unacceptable environmental impacts. This criterion was rated with high ranking strategies producing no effect on environmental resources and low ranking strategies generating adverse impacts on water quality and other resources.

6.2.1.3 Summary of Selected Adaptation Strategies

The adaptation strategy screening process resulted in the identification of five strategy concepts that are carried forward for evaluation in the Basin Study models. This section summarizes these strategy concepts by category.

Increase Supply

Additional Surface Water Storage Capacity

This strategy concept includes quantification of potential surface storage opportunities in the Upper Klamath Basin. Some examples of proposals that fall within this strategy concept are listed in Appendix E. Additional surface water storage capacity is quantified as the incremental excess water defined in the Klamath Basin Planning Model. This excess water is quantified as the remaining water after releases are made to the Klamath Project and to meet environmental needs, including instream flow needs in the Klamath River and water stored in Upper Klamath Lake to maintain elevations. For this strategy, it is assumed that the remaining water could be stored for future use; however, it is acknowledged that the 2013 Klamath Project proposed action Biological Assessment and associated Biological Opinion consider this quantity to be part of the environmental water account.

Decrease Demand

Agricultural Water Conservation

This strategy concept includes reduction in overall agricultural water demand throughout the basin by a range of percentages (between 30 percent and 50 percent). One goal of this implemented strategy concept is to determine how

much reduced agricultural demand would be needed to offset the impacts of climate change alone. Reductions in agricultural water demand might be obtained through means identified in the proposed strategy examples listed in Appendix E. These might include canal lining and pump operation optimization; crop idling, irrigated land retirement and rain-fed agriculture; shifting agricultural production to more drought tolerant crops; and converting irrigation systems to more efficient technologies along with the use of cover crops to improve soil productivity.

Additional Supply to Upper Klamath Lake

This strategy concept captures the additional 30,000 acre-feet of water provided for Upper Klamath Lake in the KHSA, KBRA, and Upper Klamath Basin Comprehensive Agreement as generated by land retirement actions in the Upper Klamath Basin. The strategy concept does not identify individual areas where water demand reduction would occur. However, this strategy assumes that the additional volume of water is made available proportionally between the Sprague River, the Williamson River upstream of its confluence with the Sprague River, and the local inflows between the confluence and Upper Klamath Lake. The proportions of the total 30,000 acre-foot volume are determined based on the relative contributions to Upper Klamath Lake inflows of mean annual flow from these three sources (Sprague River, Williamson River, and local inflows between the Sprague-Williamson confluence and Upper Klamath Lake). The goal of this strategy concept is to evaluate the effect of reductions in collective water use upstream of Upper Klamath Lake. This strategy also assumes that operating rules are not modified to compensate for the additional Upper Klamath Lake inflow.

Modify Operations

Two strategy concept options were developed to capture the adaptation strategy articulated in the screening process as “reduce environmental demand.” These strategy concepts were developed to facilitate the analysis in the Basin Study models of five strategy examples: protect cool water refugia; keep higher quality water in-stream to protect species and river ecosystems by using lower quality water for agricultural purposes; purchase water from water-rights holders and keep that flow in-stream to reduce demand on a short-term basis; curb demand with ecosystem restoration/improvements, water use effectiveness, and environmental water scarcity programs; and ensure adequate flows for fish and wildlife habitat.

Tributary Water Temperature Reduction

This strategy concept addresses the need for cold water refugia in summer months to support fish and wildlife, particularly salmonids, in the Klamath River Basin tributaries. This concept is based on existing emergency water management planning in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs. In this strategy concept, a 4 degrees Celsius (degrees C) reduction in water temperature (or about 7 degrees F) in the Scott and Shasta Rivers is assumed as input to the RBM10 stream temperature model for the Klamath River, and effects of that reduction on mainstem Klamath River temperature are evaluated.

6.2.1.4 Sensitivity of Simulated Water Temperature to Changes in Flow and Climate

This strategy concept includes exploring relationships between water temperature change and streamflow change, using historical and future climate change simulations of managed streamflow (using the Klamath RiverWare planning model) and river temperature (using the RBM10 model). By evaluating potential relationships between temperature and flow change, it may be possible to estimate the needed change in flow to obtain a desired change in Klamath River temperature. Such information may be valuable in determining what changes in water management may be needed to counter the impacts of climate change.

6.3 Uncertainties Associated with Strategy Selection

Adaptation strategies were intended to encompass a range of management actions. They were selected to be broad in scope with basin-wide implications, and not specific to any particular subbasin or singular project operation. Broad strategy concepts were selected, in part because numerous existing studies have evaluated some proposed actions in depth, and also because management conditions in the basin are dynamic. Strategies were selected with the intent that they noticeably reduce water supply and demand imbalances; however, they were selected without prior knowledge of their relative impact. Therefore, there is uncertainty as to whether the selected strategies have greater impact on system reliability than those that were not selected. In short, there may be additional strategies that could reduce water supply and demand imbalances but were not considered by the study.

In addition, strategies were initially screened on their ability to be modeled in the framework of the Basin Study. A strategy that could not be modeled by the Basin Study framework may in fact have substantial impact on system reliability; however, the impact could not be appropriately assessed with respect to that resulting from selected strategies.

6.4 Evaluation of System Reliability with Adaptation Strategies

In Chapter 5, projected response to climate change is evaluated by examining effects on basin-wide response measures and on several categories of performance measures. Basin-wide response measures include flows at key locations, river temperature, UKL storage, and Project delivery. Performance measures provide additional details on operational elements such as hydropower, flood control, recreation, and ecological resources. In the analysis described in Chapter 6, the potential for adaptation strategies to affect response to climate change is evaluated. Basin-wide response measures and system performance measures are examined, comparing the collective effects of both climate change and adaptation strategies to the effects of climate change alone.

An illustration of the model scenarios that capture these differences is visualized in Figure 6-3. The baseline scenario uses historical hydrology, and in Chapter 5 we compare results from model simulations using five future climate scenarios, for both the 2030 time horizon and the 2070 time horizon, as well as CMIP3- and CMIP5-based temperature and precipitation projections. The blue line in Figure 6-3 demonstrates this comparison. In this chapter (Chapter 6), the focus is on the effects depicted by the orange line and how these differ from the baseline comparison.

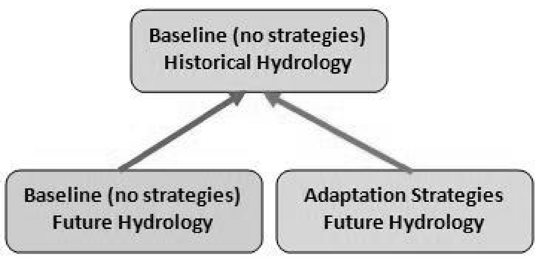


Figure 6-3. Illustration of methodology for evaluating adaptation strategy concepts

The following sections summarize projected changes in basin-wide response variables and system performance measures according to the baseline (i.e., with climate change scenarios but no adaptation strategy concepts) and adaptation strategy concepts previously discussed. Summary figures throughout this section illustrate changes in the strategy concepts associated with agricultural water conservation and additional supply to Upper Klamath Lake. The strategy concepts are defined as follows in the summary figures:

> **Baseline** – with climate change impacts, but no adaptation strategy concepts. This is similar in concept to a no action scenario.
>
> **Reduce ET 30% -** Reduction of agricultural demands throughout the basin by 30 percent
>
> **Reduce ET 50% -** Reduction of agricultural demands throughout the basin by 50 percent
>
> **Add 30KAF** – Addition of 30 KAF annually to Upper Klamath Lake inflow (contributed proportionally by Williamson River, Sprague River, and other gains, based on mean annual flow)

Results for additional strategy concepts are summarized for water quality measures. These additional strategy concepts are defined as follows in the summary figures under Section 6.4.6, Analysis of Impacts – Water Quality. Note

that this adaptation strategy concept only affects the water quality measures. Therefore, results for this measure are only summarized for these measures.

> **Reduce Shasta Scott 4degC –** Reduction of Shasta and Scott River temperatures by 4 degrees C (about 7 degrees F) year round
>
> **Add Flow 10% -** Addition of flow by 10 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River
>
> **Add Flow 20% -** Addition of flow by 20 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River
>
> **Reduce Tribs 4degC -** Reduction of temperatures by 4 degrees C (about 7 degrees F) year round in all tributaries represented in the RBM10 water temperature model. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.
>
> **Reduce Dam Outflow 4degC -** Reduction of temperatures by 4 degrees C (about 7 degrees F) year round from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

Results for the strategy concept to quantify additional surface water storage capacity are summarized under Section 6.4.7, Analysis of Impacts – Flood Control, where the mean annual Upper Klamath Lake flood control volume is quantified and evaluated. This strategy concept does not identify any specific location for additional surface water storage; however, the location for quantifying additional water is at Upper Klamath Lake.

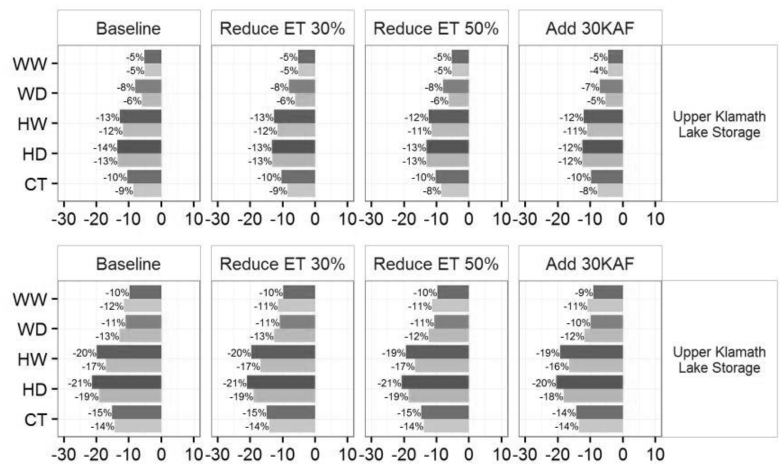
6.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of system reliability under baseline and scenarios with adaptation strategy concepts allows for an understanding of how strategies may reduce the basin's vulnerability to climate change. Similar to Chapter 5, we explore projected change in managed river flow at various locations within the basin, as well as mainstem Klamath River stream temperature.

6.4.1.1 Upper Klamath Lake Storage

Projected changes in mean annual end of month (EOM) storage in Upper Klamath Lake under baseline and strategy scenarios are summarized in Figure 6-4. Under the baseline scenario (climate change only), mean annual storage is projected to decline under all scenarios, more so for the 2070s than for the 2030s. Neither of the strategy concepts for reducing agricultural water demand (by 30 percent and 50 percent) reduce climate change impacts substantially. Percent reductions in storage conditions are minimally affected, except for the HD climate change scenario for the 2030s and for the warmer scenarios (WW and WD) for the 2070s.

Adding 30 KAF of inflow to Upper Klamath Lake does reduce the impacts of climate change by 1 to 2 percent under all climate change scenarios for both the 2030s and 2070s. Table 6-2 summarizes projected changes in storage volume under the CT scenario for both future time periods. Implementing the Add 30KAF strategy concept results in a 26 or 33 KAF reduction in mean annual storage for the 2030s, compared to 29 or 35 KAF for the baseline for CMIP3- and CMIP5-based projections, respectively. For the 2070s, the projected reduction is 46 or 48 KAF, compared to 48 or 51 KAF for the baseline.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

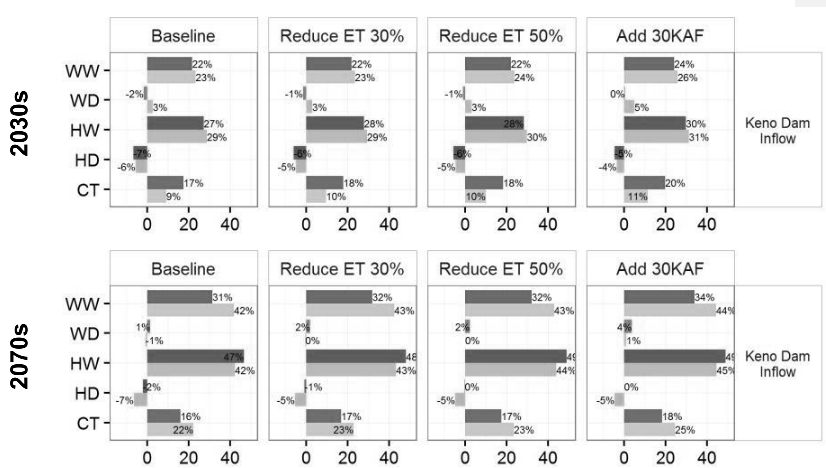
Figure 6-4. Projected change (percent) in mean annual Upper Klamath Lake storage

Table 6-2. Summary of projected change in mean annual Upper Klamath Lake Storage for the Central Tendency scenario in units of KAF

Central Tendency Scenario	CMIP	Baseline (KAF)	Reduce ET 30% (KAF)	Reduce ET 50% (KAF)	Add 30KAF (KAF)
Historical		337			
2030	CMIP3	-29	-29	-28	-26
	CMIP5	-35	-35	-34	-33
2070	CMIP3	-48	-47	-47	-46
	CMIP5	-51	-50	-50	-48

6.4.1.2 Keno Dam Inflow

Projected changes in mean annual inflow to Keno Dam under baseline and strategy scenarios are summarized in Figure 6-5. Under the baseline scenario (climate change only), mean annual inflow is projected to increase under the wetter scenarios (WW and HW) for both future time periods and decrease modestly under the drier scenarios (WD and HD), with an increase under the CT scenario projected to be 9 or 17 percent for the 2030s and 16 or 22 percent for the 2070s, depending on consideration of CMIP3- or CMIP5-based projections. Implementation of each of the strategy concepts would maintain or increase the mean annual inflow at Keno, and by similar percentages. Addition of 30 KAF of inflow to Upper Klamath Lake appears to have a larger effect on Keno inflow than does reduction in agricultural demands in the regions upstream of Keno.



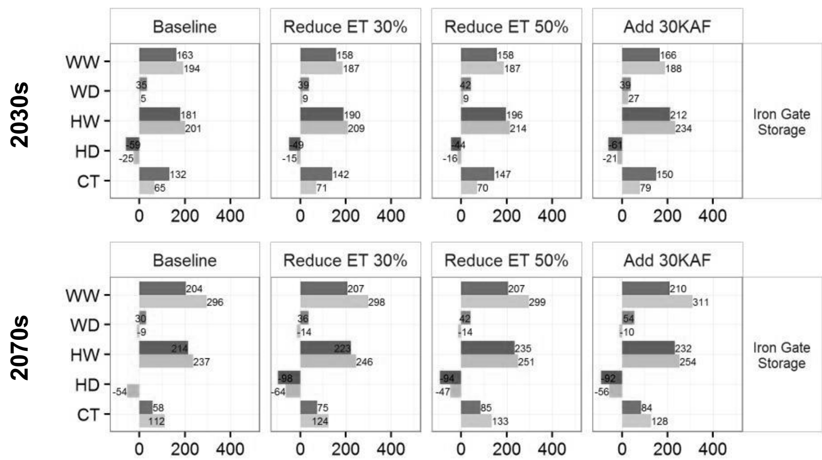
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-5. Projected change (percent) in mean annual inflow to Keno Dam

6.4.1.3 Iron Gate Reservoir Storage

Projected changes in mean annual Iron Gate Reservoir storage under baseline and strategy scenarios are summarized in Figure 6-6. Under the baseline scenario (climate change only), mean annual storage is projected to change very little on a percentage basis compared with the historical simulation. Iron Gate Reservoir elevations have not fluctuated much historically, typically staying between 55,000 acre-feet and 57,000 acre-feet. Projected changes shown in Figure 6-6 are reported in units of acre-feet. Mean annual storage is projected to increase under all scenarios and strategies, with the exception of the HD scenario for both the 2030s and 2070s time periods. Reduction of agricultural demand provides some additional storage at Iron Gate, but generally the addition of 30 KAF inflow to Upper Klamath Lake has a larger impact on Iron Gate storage. Still, all

adaptation strategy concepts do not substantially change Iron Gate storage and do not generally counter the effects of climate change.

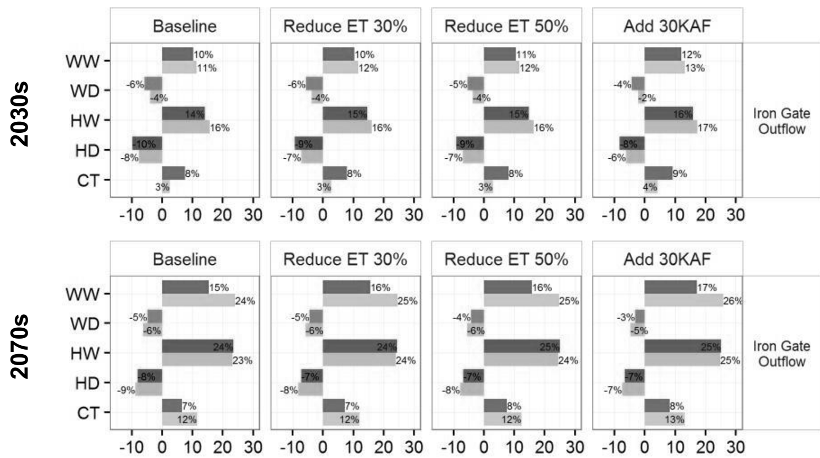


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-6. Projected change (acre-feet) in mean annual Iron Gate Reservoir storage

6.4.1.4 Iron Gate Reservoir Outflow

Projected changes in mean annual Iron Gate Reservoir outflow under baseline and strategy scenarios are summarized in Figure 6-7. Under the baseline scenario (climate change only), mean annual outflow is projected to increase under wetter scenarios (WW and HW) and decrease modestly under drier scenarios (WD and HD), with the CT scenario indicating increases of 3 or 8 percent for the 2030s and 7 or 12 percent for the 2070s. Implementation of adaptation strategies does not substantially counter climate change impacts. Reduction of agricultural demand increases the effect of additional outflow at Iron Gate, but only by about one percent for most climate change scenarios considered. Additional inflow to Upper Klamath Lake (Add 30KAF) increases the additional outflow at Iron Gate by up to 2 percent over the baseline response to climate change alone.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-7. Projected change (percent) in mean annual inflow to Iron Gate Reservoir.

6.4.1.5 Shasta River Flow

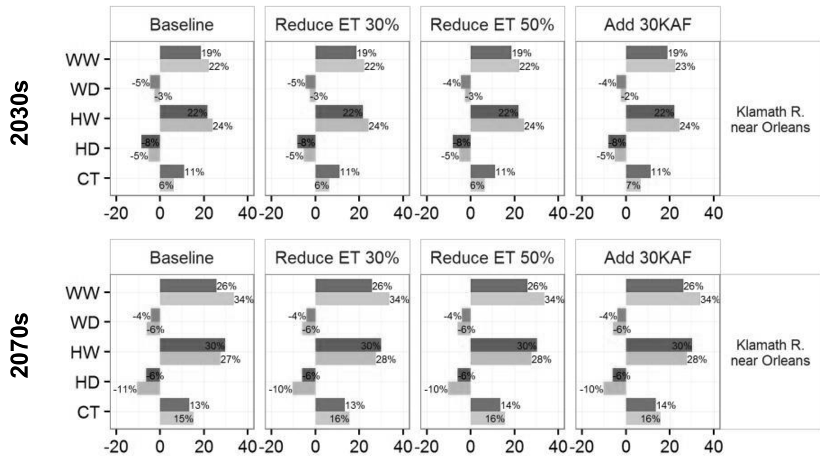
Projected changes in mean annual flow in the Shasta River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

6.4.1.6 Scott River Flow

Projected changes in mean annual flow in the Scott River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

6.4.1.7 Flow at Klamath River near Orleans

Projected change in mean annual flows in the Klamath River near Orleans under baseline and strategy scenarios is summarized in Figure 6-8. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 6 or 11 percent for the 2030s and 13 or 15 percent for the 2070s, according to model simulations. Similar to other upstream locations, reduction of agricultural demand in the contributing area to the basin upstream of Orleans results in no change for the 2030s and little change for the 2070s in simulated managed flow on a percentage basis. Additional Upper Klamath Lake inflow of 30 KAF annually has only a slightly greater impact than agricultural demand reduction.

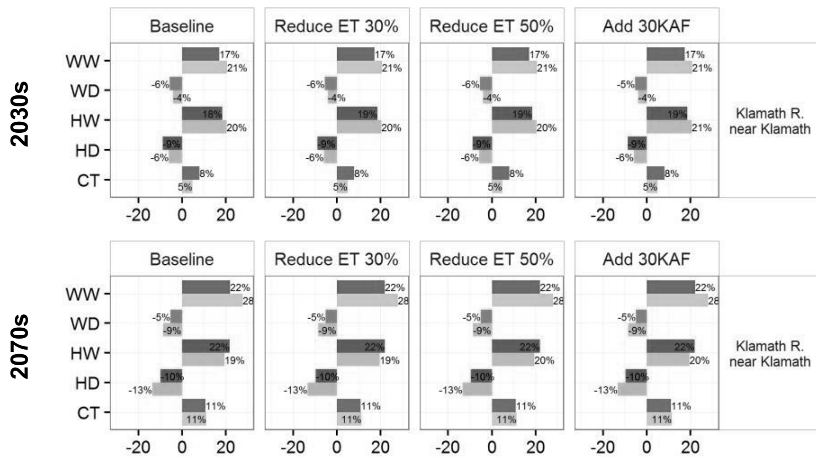


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-8. Projected change (percent) in mean annual flow at Klamath River near Orleans

6.4.1.8 Flow at Klamath River near Klamath

Projected changes in mean annual flows in the Klamath River near Klamath under baseline and strategy scenarios are summarized in Figure 6-9. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 5 or 8 percent for the 2030s and 11 percent for the 2070s, according to model simulations. Generally, the adaptation strategies either have no influence or increase flows on a mean annual basis, about one percent or less for the 2030s and no noticeable change for the 2070s. This result is in part due to the fact that any change in flow volume is a small percentage of the overall river flow at Klamath, which is close to the mouth of the basin.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-9. Projected change (percent) in mean annual flow at Klamath River near Klamath

6.4.2 Analysis of Impacts – Ability to Deliver Water

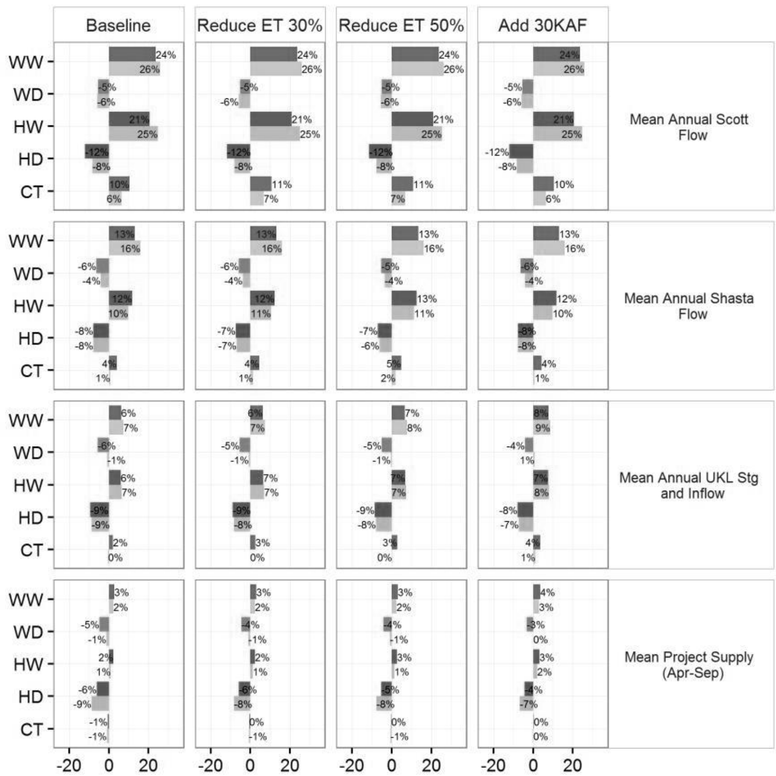
As discussed in Chapter 5, measures of the ability of the Klamath River Basin to supply water to meet human needs include (1) the April through September irrigation water supply to the Klamath Project (Project Supply), (2) mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow (Upper Klamath Lake Supply), (3) mean annual flows in the Shasta River near Yreka, and (4) mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the historical simulation period, the Upper Klamath Lake Supply parameter was about 1.38 million acre-feet. Additional measures representing the overall hydrology conditions in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

Projected changes in water supply measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-10 and for the 2070s in Figure 6-11. For the Scott and Shasta Rivers under the baseline scenario (climate change only), mean annual flow is projected to increase under wetter scenarios (WW and HW) and decrease under drier scenarios (WD and HD), with the CT scenario indicating a modest increase. For all scenarios, projected changes are greater for the 2070s time period than for the 2030s. For both rivers, reduction of agricultural demand (by 30 or 50 percent) does not appear to provide a substantial amount of additional flow volume, as indicated by no change or small change in the percent increase or decrease of mean annual flow. As expected, additional 30 KAF of inflow to Upper Klamath Lake does not impact mean annual flow in these rivers.

Projected Klamath Project Supply

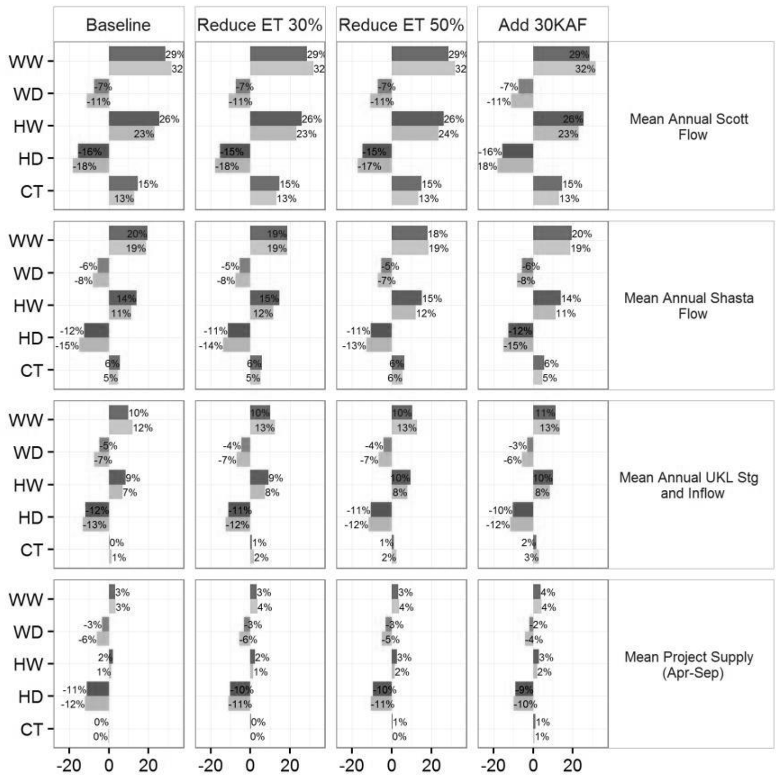
Neither reduction of agricultural demands nor additional 30 KAF inflow to Upper Klamath Lake have substantial impacts on mean Klamath Project water supply (April – September). However, the additional 30 KAF inflow does provides slightly greater additional supply than a reduction in agricultural demands.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-10. Projected change in water supply measures for the 2030s with strategies in place, expressed as percent change

For the Upper Klamath Lake Supply measure, adaptation strategy concepts either result in no change or result in small increases in this value, thereby adding to increases in the measure for those climate change scenarios where there are increases (generally wetter scenarios), or decreasing the reduction for other scenarios (generally drier scenarios). Similarly, reduction of agricultural demands and additional inflow to Upper Klamath Lake do not have substantial impacts on mean April through September Klamath Project water supply. However, an additional 30 KAF provides greater additional supply than a reduction in agricultural demands, as indicated by greater increases in supply for the wetter scenarios and small decreases for the drier scenarios, compared with the historical simulation.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-11. Projected change in water supply measures for the 2070s with strategies in place, expressed as percent change

6.4.3 Analysis of Impacts – Hydroelectric Power

As discussed in Chapter 5, hydroelectric power measures considered in this study include mean number of spill days per year and mean annual spill volume at the major mainstem Klamath River power facilities (J.C. Boyle, COPCO 1, and Iron Gate), as well as mean annual hydropower generation summed over the four mainstem dams (those listed above plus COPCO 2). For the historical simulation period, mean annual days with spill at the three facilities are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate. The number of spill days and the mean annual spill volumes for J.C. Boyle and COPCO 1 are projected to increase for most scenarios for both future time horizons under the baseline (climate change with no strategies in place). At Iron Gate the projected spill volume generally increases, although by a lower percentage than at J.C. Boyle

and COPCO 1, and the projected mean number of spill days per year shows a small decrease.

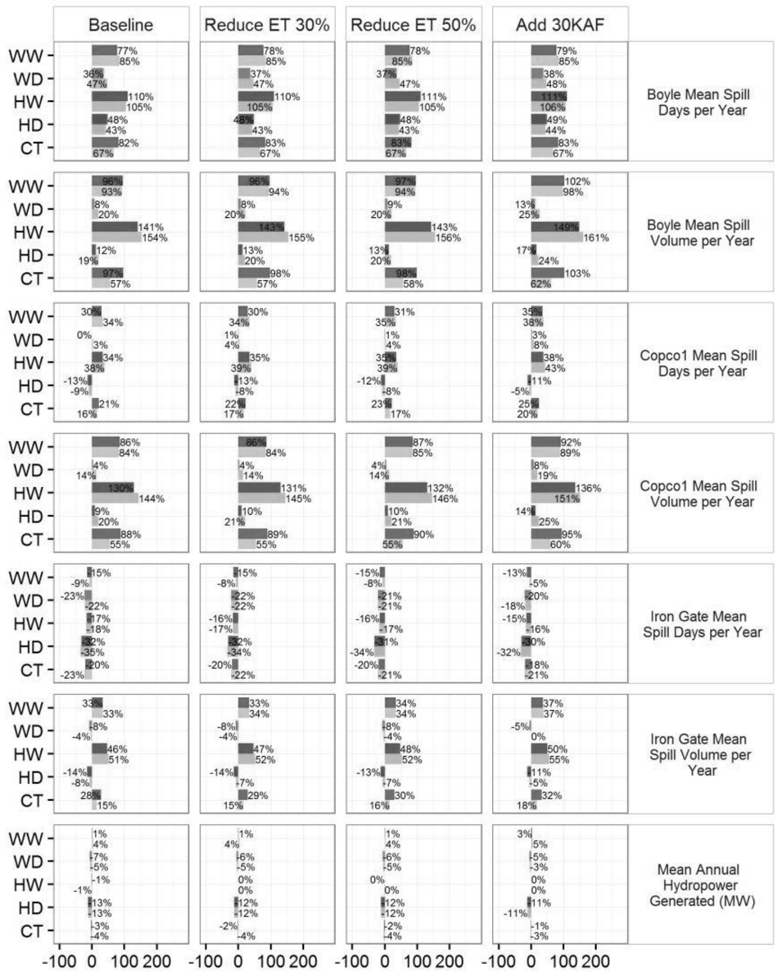
Projected changes in hydropower measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-12 and for the 2070s in Figure 6-13. The adaptation strategy concepts considered generally provide additional water to the mainstem Klamath River, thereby contributing to greater projected increases in mean number of spill days per year, mean annual spill volume, and mean annual hydropower production, more so for the 2070s than for the 2030s future time periods. Again, the addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes than does the decrease in agricultural demands. Projected changes in hydropower production are generally quite small compared with historical simulations, primarily because production under the historical simulation is on the order of 27,000 MW. In other words, hydropower production as a percentage does not change substantially due to the magnitude of hydropower production. Table 6-3 summarizes projected changes in mean annual hydropower production under the CT scenario for both future time periods. Implementation of the Add 30KAF strategy concept results in a 714 or 352 MW reduction in mean annual production for the 2030s, compared to 1,146 or 749 MW for the baseline (depending on consideration of CMIP3- or CMIP5-based projections). For the 2070s, the projected reduction is 468 or 1,209 MW, compared to 818 or 1,593 MW for the baseline.

Projected Hydropower Production

The addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes in hydropower production than does the decrease in agricultural demands. Hydropower production as a percentage does not change substantially due to the magnitude of hydropower production (27,000 MW, according to historical simulations).

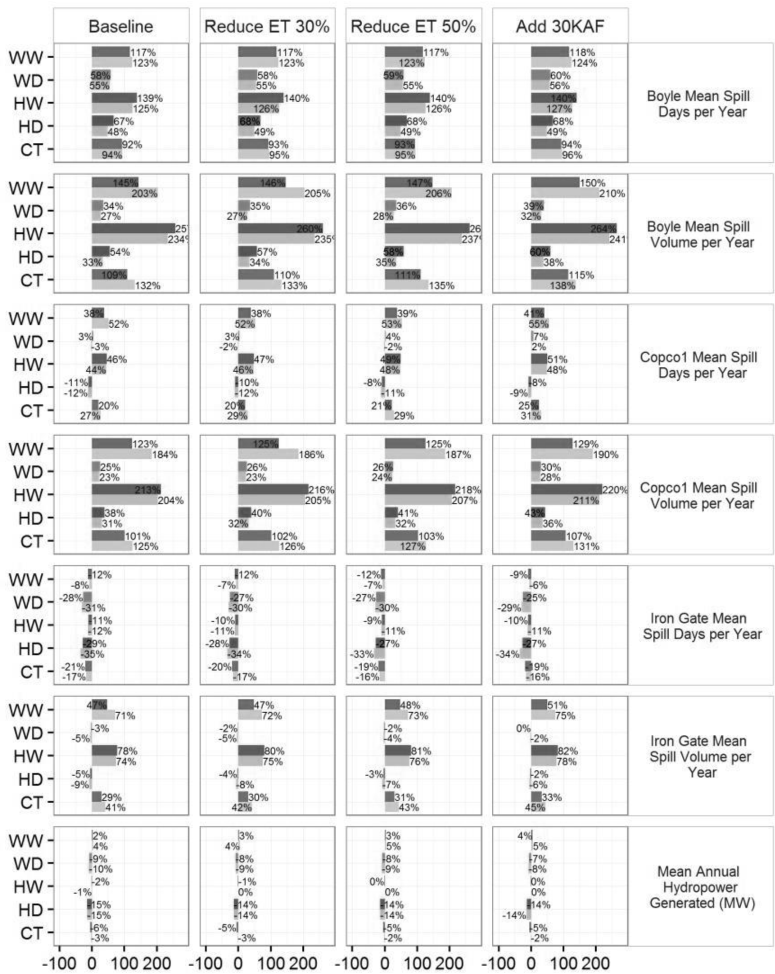
Table 6-3. Summary of projected change in mean annual hydropower production for the Central Tendency scenario in units of MW

Central Tendency Scenario	CMIP	Baseline (MW)	Reduce ET 30% (MW)	Reduce ET 50% (MW)	Add 30KAF (MW)
Historical		26,741			
2030	CMIP3	-1,146	-1,026	-959	-714
	CMIP5	-749	-637	-569	-352
2070	CMIP3	-818	-672	-585	-468
	CMIP5	-1,593	-1,410	-1,290	-1,209



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-12. Projected change in hydroelectric power measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-13. Projected change in hydroelectric power measures for the 2070s with strategies in place, expressed as percent change

6.4.4 Analysis of Impacts – Recreation

Recreation impacts are measured based on mean annual river boating days and mean annual fishing days in various reaches of the Klamath River. As discussed in Chapter 5, recommended flow ranges were summarized in the Environmental Impact Statement/Report for dam removal (Interior and CDFG, 2012). For the

historical simulations, mean annual number of fishing days are generally greater than mean annual number of river boating days. Projected changes in fishing measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-14 and for the 2070s in Figure 6-15, while projected changes in boating measures are summarized similarly in Figure 6-16 and Figure 6-17. For fishing under the baseline scenario (climate change with no strategies in place), the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios indicate decreases in the number of fishing days for both future time horizons. These results show that recommended flow ranges for fishing do not favor high flows. Because the adaptation strategy concepts generally result in greater mainstem river flows, their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The projected changes are small on a percentage basis (on the order of 1 to 2 percent). Implementation of the strategies does not counter the effects of climate change on fishing days.

Recreation

Adaptation strategy concepts generally result in greater mainstem river flows and their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The implementation of adaptation strategy results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario.

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. The implementation of adaptation strategy concepts (both agricultural demand reduction and additional inflow to Upper Klamath Lake) results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario. The strategies do not have a noticeable impact on boating recreation measures downstream of Iron Gate Dam. Upstream of Iron Gate, the strategies cause changes in the boating recreation measures by up to 2 percent for the 2030s and up to 4 percent for the 2070s, and more so for the Add 30KAF strategy scenario than for the agricultural demand reduction scenarios.

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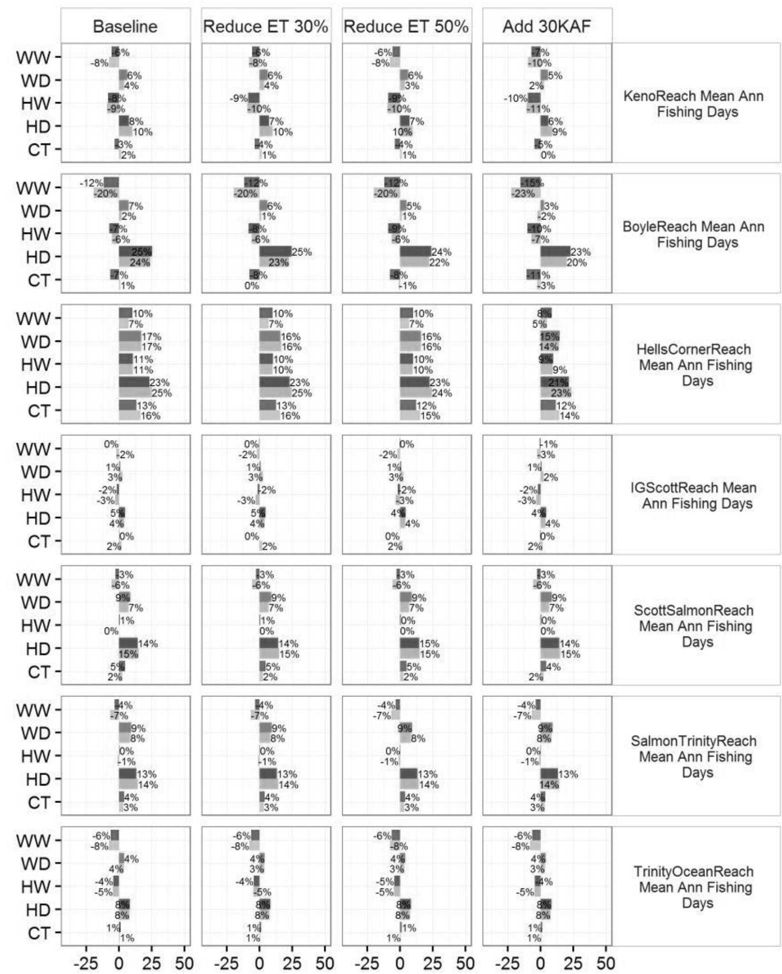
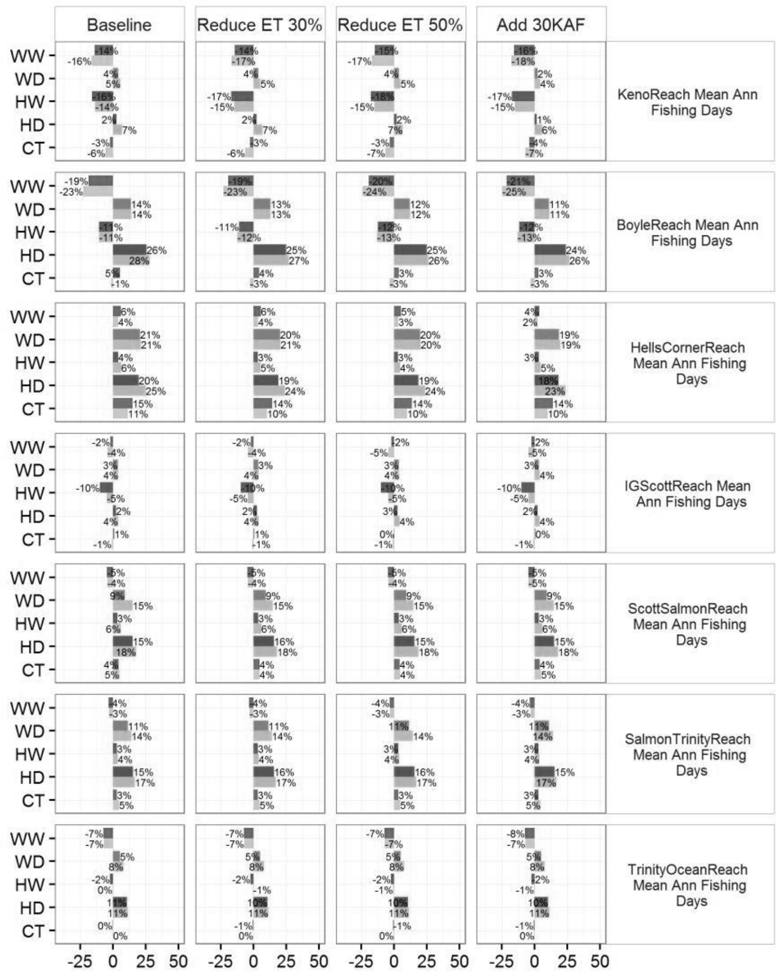


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-14. Projected change in fishing recreation measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-15. Projected change in fishing recreation measures for the 2070s with strategies in place, expressed as percent change

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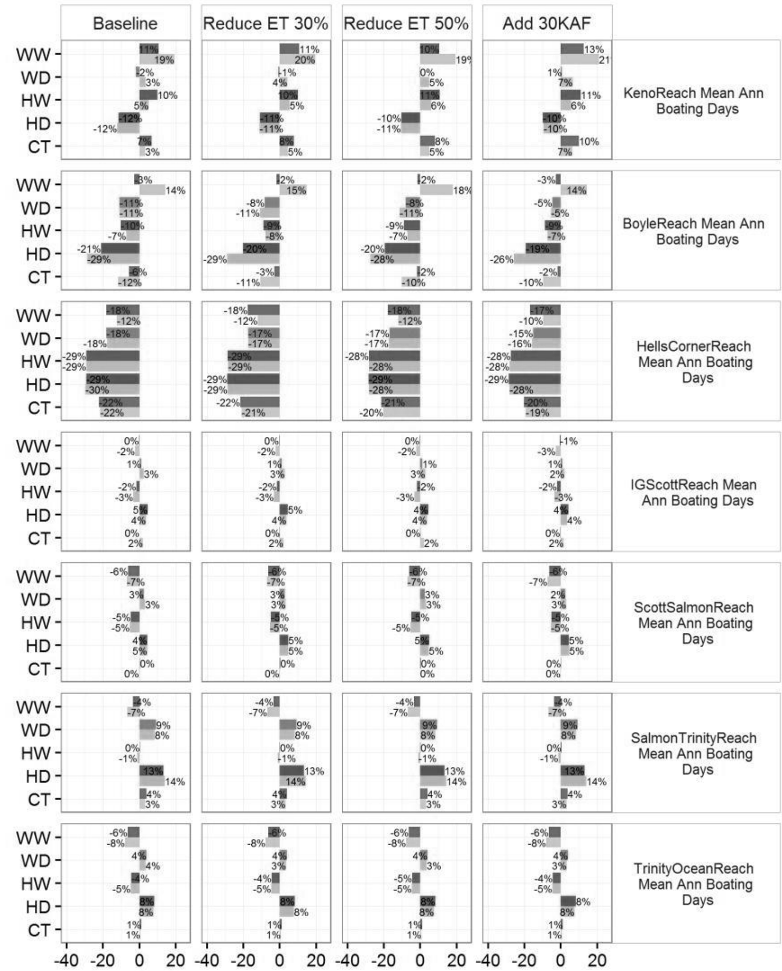
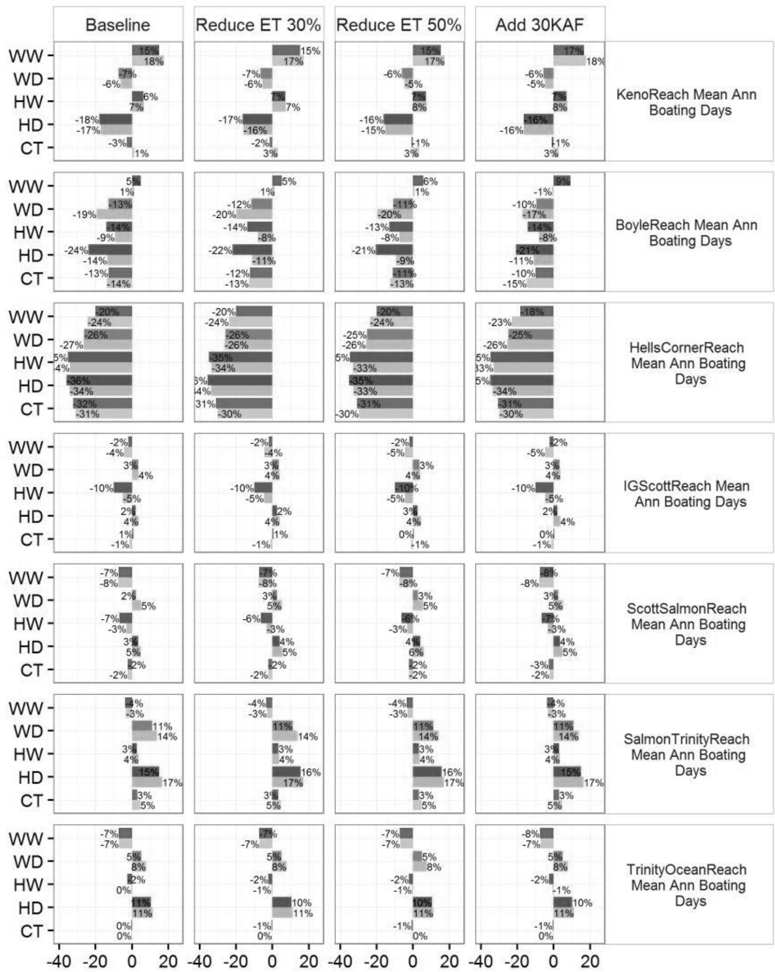


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-16. Projected change in river boating recreation measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-17. Projected change in river boating recreation measures for the 2070s with strategies in place, expressed as percent change

6.4.5 Analysis of Impacts – Ecological Resources

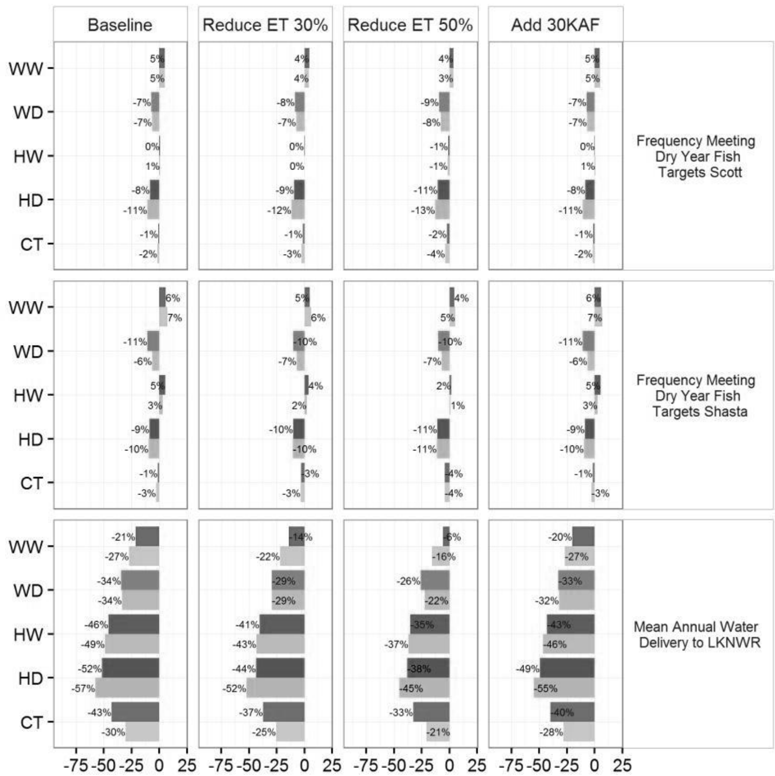
As discussed in Chapter 5, ecological resources measures considered in this study are related to needs for fish and wildlife habitat, including flow targets for SONCC ESU salmon and water supply to Lower Klamath National Wildlife Refuge (LKNWR). According to model simulations under historical hydrology, recommended flow targets that were developed specifically for the Shasta River

Basin were met 57 percent of days for the Shasta River and 71 percent of days for the Scott River (which has higher mean annual flow than the Shasta River).

Projected change in water supply measures under Baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-18 and for the 2070s in Figure 6-19. Projected changes under the baseline in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers indicate increases on a percentage basis for the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and WD), with greater change projected for the 2070s time horizon compared with the 2030s. The baseline CT scenario indicates modest decreases in the frequency of meeting recommended flow targets. The Add 30KAF strategy does not impact flows in the Scott and Shasta Rivers, so the percent change under this strategy is identical to that of the baseline scenario. A reduction in agricultural demand in these basins appears to improve the ability to meet dry year fish targets for some scenarios, but not all.

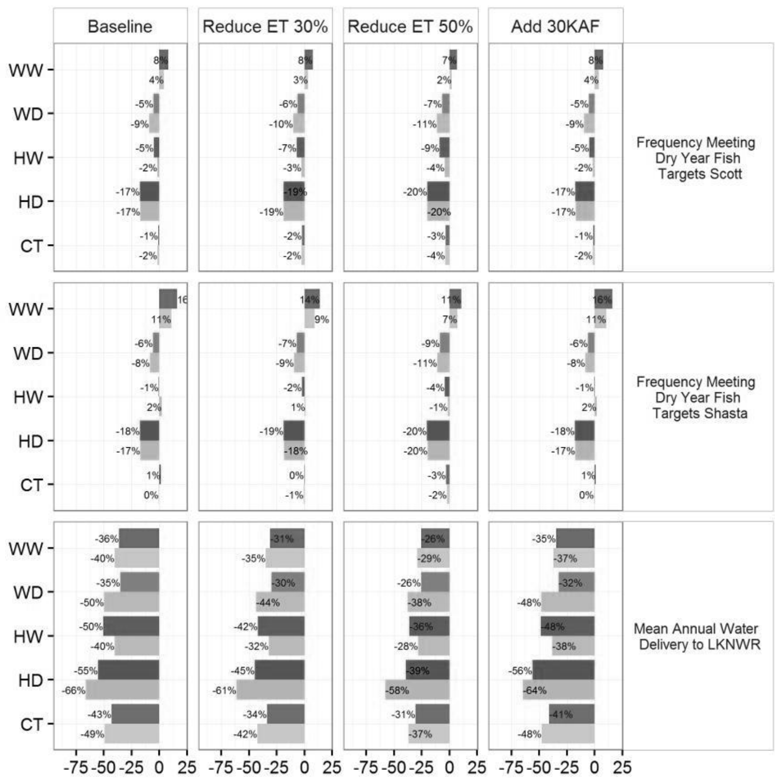
Ecological Resources Impacts

The addition of 30 KAF of inflow to Upper Klamath Lake does not impact flows in the Scott and Shasta Rivers. Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. The additional Upper Klamath Lake inflow scenario also results in greater supply to the refuge, although to a lesser degree.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-18. Projected change in ecological resources measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-19. Projected change in ecological resources measures for the 2070s with strategies in place, expressed as percent change

Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. For the 2030s, the projected reduction in water supply to LKNWR under the CT climate change scenario goes from a reduction of 30 or 43 percent (depending on the use of CMIP3 or CMIP5 scenarios) to a reduction of 21 or 33 percent if agricultural demands are cut in half. The Add 30KAF scenario also results in greater supply to the refuge, although to a lesser degree. For the 2070s, a 50 percent reduction in agricultural demands results in a change in the measure from 43 or 49 percent (under the baseline scenario) to 41 or 48 percent.

It may be noted that model results indicate a decrease in deliveries to LKNWR under all adaptation strategy concepts, albeit to a lesser extent than the baseline

scenario (climate change only). These results may in part be due to the fact that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Since Klamath Project supply is not projected to change substantially as a result of adaptation strategies, projected additional releases from Upper Klamath Lake may provide a greater benefit to the refuge.

6.4.6 Analysis of Impacts – Water Quality

As discussed in Chapter 5, water quality measures considered in this study are related to Klamath River temperature. The SONCC ESU salmon recovery plan (NMFS, 2012) provides a classification of river conditions based in part on the maximum weekly average temperature (MWAT). River temperatures were simulated using the RBM10 water temperature model developed by Perry et al. (2010). According to model simulations under historical hydrology, the river temperatures (as defined by the MWAT) for all simulated years were classified as "poor" under the salmon recovery plan. The "poor" classification threshold is 63.68 degrees F, or 17.6 degrees C. The measure considered by the basin study is the mean annual MWAT.

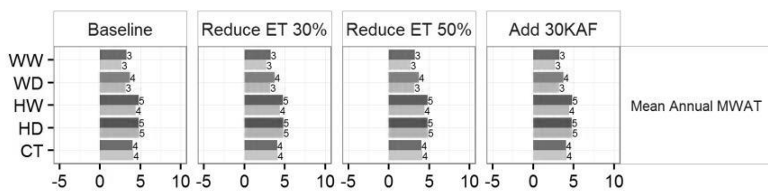
> **Water Quality Impacts**
>
> Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on water quality measures. Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow.

Projected changes in water quality measures under baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-20 and Figure 6-21 and for the 2070s in Figure 6-22 and Figure 6-23. It should be noted that additional adaptation strategy concepts were considered that affect river temperature. One additional strategy (labeled "Reduce Scott Shasta 4degC") focuses on reducing river temperature in the Scott and Shasta rivers by 4 degrees C (about 7 degrees F), in accordance with an existing emergency water management plan in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs.

Other additional strategies fall under the adaptation strategy concept of evaluating the sensitivity of river temperature to changes in tributary river temperature or streamflow. These strategies include adding 10 or 20 percent of flow to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River. These strategies are labeled as "Add Flow 10%" and "Add Flow 20%", respectively. They also include reducing input river temperatures in different locations represented in the RBM10 model. These strategies are labeled "Reduce Tribs 4degC" and "Reduce Dam outflow 4degC." "Reduce Tribs 4degC" includes reduction in temperature for all

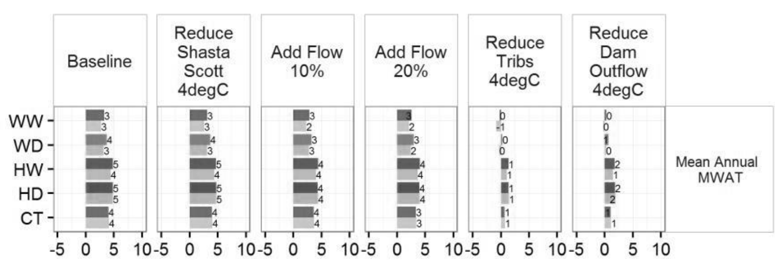
tributaries represented in the RBM10 model. "Reduce Dam Outflow 4degC" includes reducing outflow temperatures by 4 degrees C from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River.

Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on either water quality measure. The 2030s time period (summarized by Figure 6-20) shows no change, while the 2070s time period (summarized by Figure 6-22) shows no change based on reduction of agricultural demand by 30 percent and minimal change for the other two strategies. Figures 6-21 and 6-23 illustrate that Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow. Increasing tributary flows by 20 percent has a minimal impact on Klamath River temperatures, while reducing river temperature at specific locations (where possible) results in countering climate change effects substantially, although less so by the 2070s.



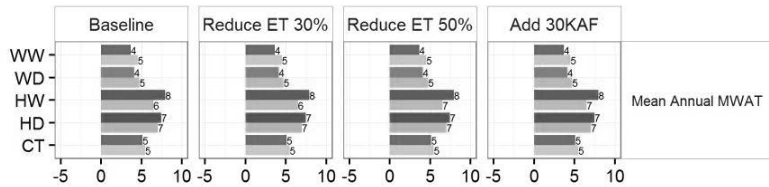
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-20. Projected change in water quality measures for the 2030s with strategies in place, expressed as degrees C



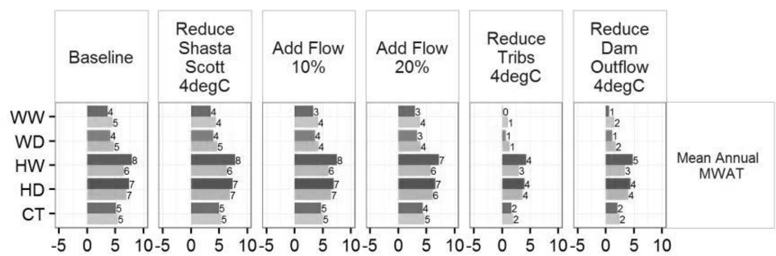
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-21. Projected change in water quality measures for the 2030s with additional strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-22. Projected change in water quality measures for the 2070s with strategies in place, expressed as degrees C



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-23. Projected change in water quality measures for the 2070s with additional strategies in place, expressed as percent change

6.4.7 Analysis of Impacts – Flood Control

As discussed in Chapter 5, flood control measures include (1) the frequency (mean number of days per year) of flood control releases from Upper Klamath Lake, (2) the mean annual flood control release volume (based on water year) from Upper Klamath Lake, and (3) the date of seasonal peak flow at three locations (J.C. Boyle Reservoir, COPCO 1 Reservoir, and Iron Gate Reservoir). Measures are computed using results from the Klamath Basin RiverWare model. Again, flood control release from Upper Klamath Lake is defined in the 2012 Proposed Action for Klamath Project Operations (Reclamation, 2012d), which is quantified as the release beyond that made to meet Klamath Project deliveries and to meet instream flow needs. Projected change in Upper Klamath Lake flood control measures under baseline and adaptation strategy concept scenarios are summarized in Figure 6-24 (2030s) and Figure 6-25 (2070s). Table 6-4 quantifies the difference between projected flood control release volume in units of KAF and the historical baseline, which addresses the question of how much additional surface water may be available for future storage under the “Additional Surface Water Storage Capacity” strategy concept.

The frequency of Upper Klamath Lake flood control release under the historical simulation is about 44 percent of days, while the corresponding mean annual flood control release volume is approximately 224 KAF. As previously discussed, flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. Even under historical hydrology, 44 percent of days may seem high for the percent of days of flood control release from Upper Klamath Lake. The characterization of flood control release is consistent between the RiverWare model and the KBPM. However, greater simulated flows in the Lost River system, compared with KBPM, may result in smaller demand from Upper Klamath Lake for Klamath Project supply, and therefore greater flood control release.

Flood Control Impacts

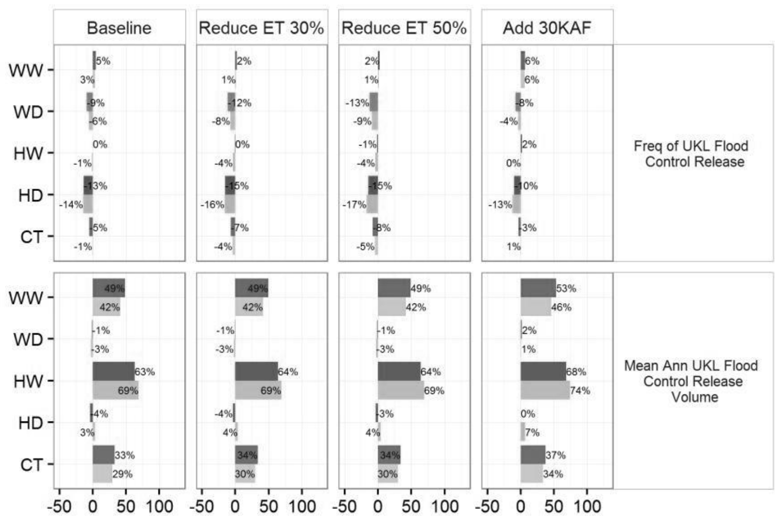
The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume. Model results indicate substantial surface water available for storage in a future climate, due to a combination of decreased snowpack and increased precipitation on an annual basis. Adaptation strategy concepts have small effects on the mean date of seasonal peak flow, indicating a difference of 2 days or less.

Projected changes indicate minimal change for the wetter scenarios (WW and HW) and a decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. At the same time, for all scenarios there is a projected increase in the mean annual flood control volume, suggesting that more water is being released in the future even though the occurrence of release may be decreasing.

Under adaptation strategy concepts in which there is a reduction in agricultural demands, additional water causes greater increases in flood control release for the wetter scenarios, and smaller decreases for the drier scenarios. The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume.

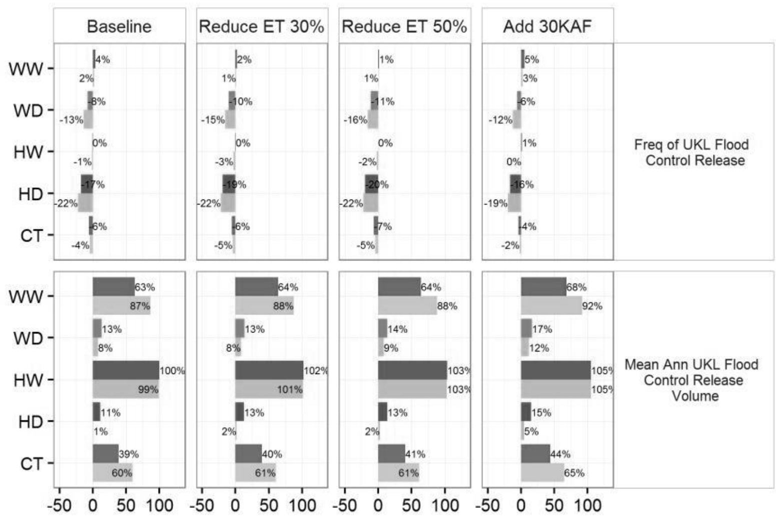
Projected changes in the date of seasonal peak flow are less substantial at J.C. Boyle Reservoir than at COPCO 1 and Iron Gate dams (refer to Table 6-5 through Table 6-7). The baseline scenario dates of seasonal peak flow are April 9 at J.C. Boyle, April 17 at COPCO 1, and April 15 at Iron Gate. Projected baseline scenario climate change effects at J.C. Boyle range from 1 to 4 days later for the 2030s to 4 days earlier to 3 days later for the 2070s, depending on the climate scenario. For COPCO 1 and Iron Gate, projected changes range from 1 day later to 9 days earlier for the 2030s and about 2 days to 2 weeks earlier for the 2070s.

Considering the adaptation strategy concepts and their effect on mean date of seasonal peak flow, both reduction of agricultural demand and addition of 30 KAF of inflow to Upper Klamath Lake have small effects, generally resulting in peak flow dates that are different by 2 days or less from the baseline. This is true at all three dam locations evaluated.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-24. Projected change in flood control measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-25. Projected change in flood control measures for the 2070s with strategies in place, expressed as percent change

Because the mean annual Upper Klamath Lake flood control release volume is a system performance measure and is also the variable used to quantify the adaptation strategy concept pertaining to additional storage volume, we summarize the projected flood control release volume for all climate change scenarios at both future time horizons. According to model simulations and the means of quantifying flood control release (i.e., that release volume beyond Klamath Project deliveries and environmental flow releases), there may be substantial additional surface water available for storage under future climate conditions. This volume may be due to projected increases in precipitation and/or the reduction in snowpack storage as temperatures are projected to warm.

Table 6-4. Projected change in mean annual Upper Klamath Lake flood control release volume, computed as difference (in units of KAF) between scenario and historical baseline

Scenario	Period	BCSD Projection	Baseline (KAF)	Reduce ET 30% (KAF)	Reduce ET 50% (KAF)	Add 30KAF (KAF)
Historical	Historical	-	224			
Warm Dry	2030	CMIP-3	-6	-5	-5	2
Warm Dry	2030	CMIP-5	-3	-2	-2	5
Warm Wet	2030	CMIP-3	94	94	94	103
Warm Wet	2030	CMIP-5	110	111	111	120
Hot Dry	2030	CMIP-3	8	9	9	16
Hot Dry	2030	CMIP-5	-9	-8	-7	1
Hot Wet	2030	CMIP-3	155	156	156	167
Hot Wet	2030	CMIP-5	142	144	145	153
Central Tendency	2030	CMIP-3	67	67	68	76
Central Tendency	2030	CMIP-5	75	76	77	84
Warm Dry	2070	CMIP-3	19	19	20	27
Warm Dry	2070	CMIP-5	30	31	31	38
Warm Wet	2070	CMIP-3	195	197	198	207
Warm Wet	2070	CMIP-5	143	144	144	153
Hot Dry	2070	CMIP-3	2	5	6	12
Hot Dry	2070	CMIP-5	25	29	31	35
Hot Wet	2070	CMIP-3	224	228	231	236
Hot Wet	2070	CMIP-5	224	230	232	236
Central Tendency	2070	CMIP-3	135	137	138	147
Central Tendency	2070	CMIP-5	87	89	92	99

Table 6-5. Projected change in date of seasonal peak flow at J.C. Boyle Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle
Historical	Historical	-	April 9	-	-	-
Warm Dry	2030	CMIP-3	4	4	4	4
Warm Dry	2030	CMIP-5	4	4	4	3
Warm Wet	2030	CMIP-3	2	2	2	2
Warm Wet	2030	CMIP-5	2	2	2	2
Hot Dry	2030	CMIP-3	4	4	4	3
Hot Dry	2030	CMIP-5	4	4	4	3
Hot Wet	2030	CMIP-3	1	1	1	1
Hot Wet	2030	CMIP-5	2	2	2	2
Central Tendency	2030	CMIP-3	3	3	3	3
Central Tendency	2030	CMIP-5	2	2	2	1
Warm Dry	2070	CMIP-3	2	4	3	2
Warm Dry	2070	CMIP-5	3	3	3	3
Warm Wet	2070	CMIP-3	2	2	2	1
Warm Wet	2070	CMIP-5	2	2	2	2
Hot Dry	2070	CMIP-3	3	4	3	2
Hot Dry	2070	CMIP-5	1	2	2	1
Hot Wet	2070	CMIP-3	-2	1	-2	-3
Hot Wet	2070	CMIP-5	-4	-3	-3	-4
Central Tendency	2070	CMIP-3	0	3	0	0
Central Tendency	2070	CMIP-5	2	2	2	2

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

Table 6-6. Projected change in date of seasonal peak flow at COPCO 1 Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1
Historical	Historical	-	April 17	-	-	-
Warm Dry	2030	CMIP-3	1	1	1	1
Warm Dry	2030	CMIP-5	0	0	0	0
Warm Wet	2030	CMIP-3	-4	-4	-4	-5
Warm Wet	2030	CMIP-5	-5	-5	-5	-5
Hot Dry	2030	CMIP-3	-4	-3	-3	-4
Hot Dry	2030	CMIP-5	-3	-3	-3	-3
Hot Wet	2030	CMIP-3	-9	-9	-9	-9
Hot Wet	2030	CMIP-5	-8	-8	-8	-8
Central Tendency	2030	CMIP-3	-3	-4	-3	-4
Central Tendency	2030	CMIP-5	-6	-6	-6	-6
Warm Dry	2070	CMIP-3	-5	-5	-4	-5
Warm Dry	2070	CMIP-5	-2	-2	-2	-2
Warm Wet	2070	CMIP-3	-7	-7	-7	-7
Warm Wet	2070	CMIP-5	-7	-7	-7	-7
Hot Dry	2070	CMIP-3	-8	-7	-7	-8
Hot Dry	2070	CMIP-5	-8	-8	-8	-8
Hot Wet	2070	CMIP-3	-15	-15	-14	-15
Hot Wet	2070	CMIP-5	-17	-17	-17	-17
Central Tendency	2070	CMIP-3	-10	-10	-10	-11
Central Tendency	2070	CMIP-5	-7	-7	-7	-7

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

Table 6-7. Projected change in date of seasonal peak flow at Iron Gate Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate
Historical	Historical	-	April 15	-	-	-
Warm Dry	2030	CMIP-3	1	1	1	0
Warm Dry	2030	CMIP-5	0	0	0	0
Warm Wet	2030	CMIP-3	-4	-4	-4	-4
Warm Wet	2030	CMIP-5	-5	-5	-5	-5
Hot Dry	2030	CMIP-3	-4	-4	-4	-4
Hot Dry	2030	CMIP-5	-3	-3	-3	-3
Hot Wet	2030	CMIP-3	-9	-9	-9	-9
Hot Wet	2030	CMIP-5	-8	-8	-8	-8
Central Tendency	2030	CMIP-3	-4	-4	-4	-4
Central Tendency	2030	CMIP-5	-6	-5	-5	-6
Warm Dry	2070	CMIP-3	-5	-5	-5	-5
Warm Dry	2070	CMIP-5	-2	-2	-2	-2
Warm Wet	2070	CMIP-3	-7	-7	-7	-7
Warm Wet	2070	CMIP-5	-7	-7	-7	-7
Hot Dry	2070	CMIP-3	-7	-7	-7	-7
Hot Dry	2070	CMIP-5	-8	-8	-7	-8
Hot Wet	2070	CMIP-3	-14	-14	-13	-14
Hot Wet	2070	CMIP-5	-16	-16	-15	-16
Central Tendency	2070	CMIP-3	-10	-10	-10	-10
Central Tendency	2070	CMIP-5	-7	-7	-7	-7

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

6.5 Key Findings and Next Steps

Klamath River water users and stakeholders have long have long called for a comprehensive and integrated approach to water management to balance the needs of all water users. The Basin Study Report evaluates current and projected future water supply and demand assessments to refine existing projections of climate change's effect on the Klamath River Basin, and provide stakeholders in the region the opportunity to identify and evaluate potential adaptation strategies which may reduce identified imbalances. These adaptation strategies provide water users, stakeholders, and Reclamation with understanding of the degree to which actions including those to increase supply, decrease demand, and modify operations could reduce supply and demand imbalances that are projected to increase as a result of climate change. The Basin Study builds on earlier work and is the next significant step in developing a comprehensive knowledge base

and suite of tools and options that could address the risks posed by Klamath River Basin water supply-demand imbalances.

Results from model simulations with and without adaptation strategy concepts in place indicate that the strategies have modest abilities to reduce climate change impacts. Considered strategies include agricultural water conservation, additional inflow to Upper Klamath Lake, quantification of potential surface water storage, and evaluation of changes in flow and tributary temperature on Klamath River temperature at Klamath, California.

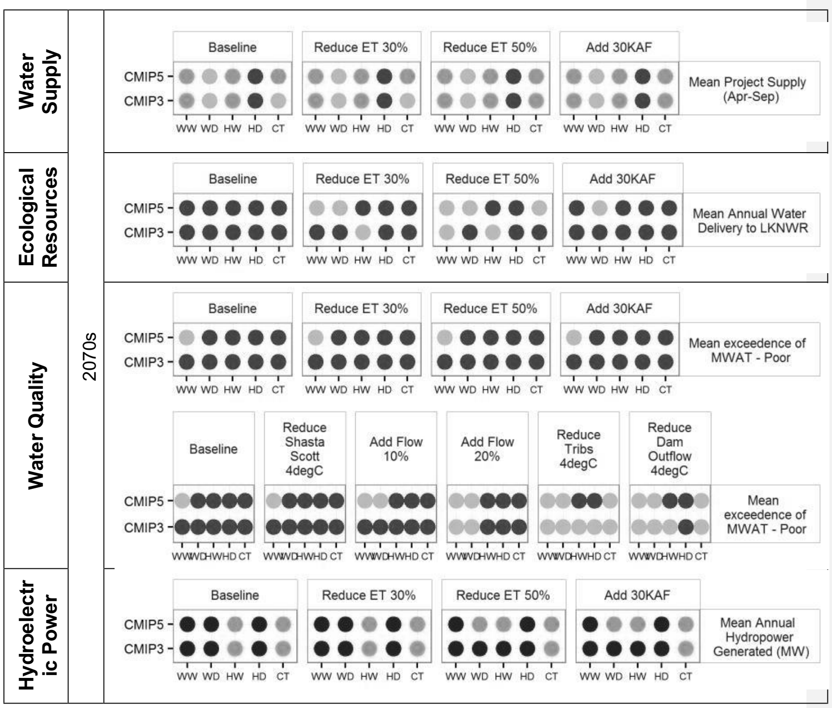
The addition of inflow to Upper Klamath Lake appears to result in the greatest change in computed basin-wide response variables and selected performance measures. With respect to sensitivities of river temperature, the reduction in tributary temperature has a greater impact than does change in flow. Also, according to model simulations, substantial surface water may be available for storage in the future due to reduction in snowpack storage and projected changes in precipitation timing and volume. The location for quantification of additional storage is at Upper Klamath Lake; however, this study does not explore locations for future surface water storage.

Figure 6-26 summarizes projected changes in four select system performance measures for the 2070s future time period, compared with the historical simulation. Projected changes are computed using CMIP3- and CMIP5-based projections, and for each of the five climate change scenarios. The baseline scenario represents climate change only, without adaptation strategy concepts in place. The other scenarios represent changes with adaptation strategy concepts. For this figure, projected changes on a percentage basis were divided into four bins: two bins for positive change and two bins for negative change. Darker circles represent the bin with greater change. Green circles indicate an improvement in the selected measure, while red circles indicate a worsening of the measure. The results summarized in the figure allow for a high level understanding of the direction of change, and highlight which strategies provide the greatest change compared with the baseline scenario.

In Figure 6-26, with respect to mean April–September Klamath Project supply, neither reduction in agricultural demand nor additional Upper Klamath Lake inflow of 30 KAF cause a substantial change compared with the baseline scenario. For mean annual water supply to LKNWR, reduction in agricultural demands results in a meaningful improvement, compared with the baseline scenario. For mean exceedance of the “poor” water quality classification (through calculation of the MWAT), reduction in tributary water temperatures has a greater influence on resulting river temperatures than changes in streamflow. It is likely not realistic to expect a reduction in temperatures in unmanaged tributaries, but changes in managed flows (i.e., Link River, Shasta River, Scott River, Trinity River) still have a meaningful impact, compared with the baseline scenario. For mean annual hydropower generation, it is apparent that climate change, and adaptation strategy concepts, result in greater hydropower production. Reduction

of agricultural demands by 50 percent and additional Upper Klamath Lake inflow of 30 KAF result in noticeable change from the baseline, while a less substantial reduction in agricultural demands (30 percent) does not provide substantial additional benefit.

Overall, climate change adversely affects mean annual deliveries to LKNWR and river temperatures; it may adversely affect or may be favorable to mean Klamath Project Supply (April–September) depending on the climate change scenario, and is likely to be favorable to mean annual hydropower production. Adaptation strategy concepts evaluated in the Basin Study do not substantially counter the effects of climate change. However, in general the addition of 30 KAF inflow to Upper Klamath Lake appears to have a greater benefit to the system reliability than does reduction in agricultural demands, based on model simulations.



Notes: Green circles indicate an improvement in the measure for the future, while red circles indicate a worsening in the measure for the future. Darker circles indicate greater change than lighter circles.

Figure 6-26. Summary of projected changes in select measures for the 2070s, with and without strategies in place

6.5.1 Refinement of Adaptation Strategies and Next Steps

The Basin Study Report indicates that implementation of projects to improve water supply, decrease demand, and modify operations can provide some improvement in the reliability and sustainability of the Klamath River system to help meet current and future water demands. The adaptation strategies evaluated in this Basin Study would all need to be further studied to refine the understanding of these potential benefits and develop plans for their implementation. Similar to this Basin Study, the agencies and stakeholders that would need to be involved in that refinement process would need to include all those potentially affected by their implementation.

The Klamath River Basin Study relied on projected future conditions that were developed utilizing existing model frameworks and inputs. Identified adaptation strategies evaluated by the Basin Study are general (i.e., not specific proposed projects) by design and are intended to identify sensitivities of the Klamath Basin to various types of potential actions. Moving forward, a number of tasks have been identified to further enhance our understanding of climate change impacts on the Klamath River Basin.

- Refinement of ecosystem demands and vulnerabilities – Additional analysis of the relationship between changes in the climate, changes in the demands of aquatic, wetland, and riparian ecosystems that result from changes in the climate, and the ability to accommodate these demands with existing supplies would further support and refine the findings in this study. Additionally, incorporation of developing river temperature modeling for the Trinity River by the U.S. Geological Survey could enhance our understanding of climate change impacts and implemented adaptation strategies on river temperatures.

- Coupled groundwater/surface water model development – Expansion of existing groundwater models for the Scott and Shasta rivers to cover broader portions of the basin would further support the analysis completed in this Basin Study.

- Reservoir Operations Refinement – Current funding by the Bureau of Reclamation Office of Policy for a Klamath River Basin reservoir operations pilot study on Upper Klamath Lake will enhance the ability to quantify Upper Klamath Lake inflows and provide for an improved understanding of Upper Klamath Lake operations.

- Effects of future policy changes – Evolving policy conditions are anticipated in the Klamath River Basin relating to future ESA consultations and potential removal of the four mainstem Klamath River dams. Continued analysis of future policies using the Basin Study modeling framework will allow for comparisons to be made, and for greater understanding of potential climate change impacts.

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Perry, R.W., J.C. Risley, S.J. Brewer, E.C. Jones, and D.W. Rondorf. 2011. *Simulating Daily Water Temperatures of the Klamath River under Dam Removal and Climate Change Scenarios.* U.S. Geological Survey Open-File Report 2011-1243. 78 p.

U.S. Department of the Interior and California Department of Fish and Game. 2012. *Klamath Facilities Removal Final Environmental Impact Statement/Environmental Impact Report.* State Clearinghouse No. 2010062060.

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17-01174_013489;17-01174_013489

RECLAMATION

Managing Water in the West

17-01174_013490;17-01174_013490

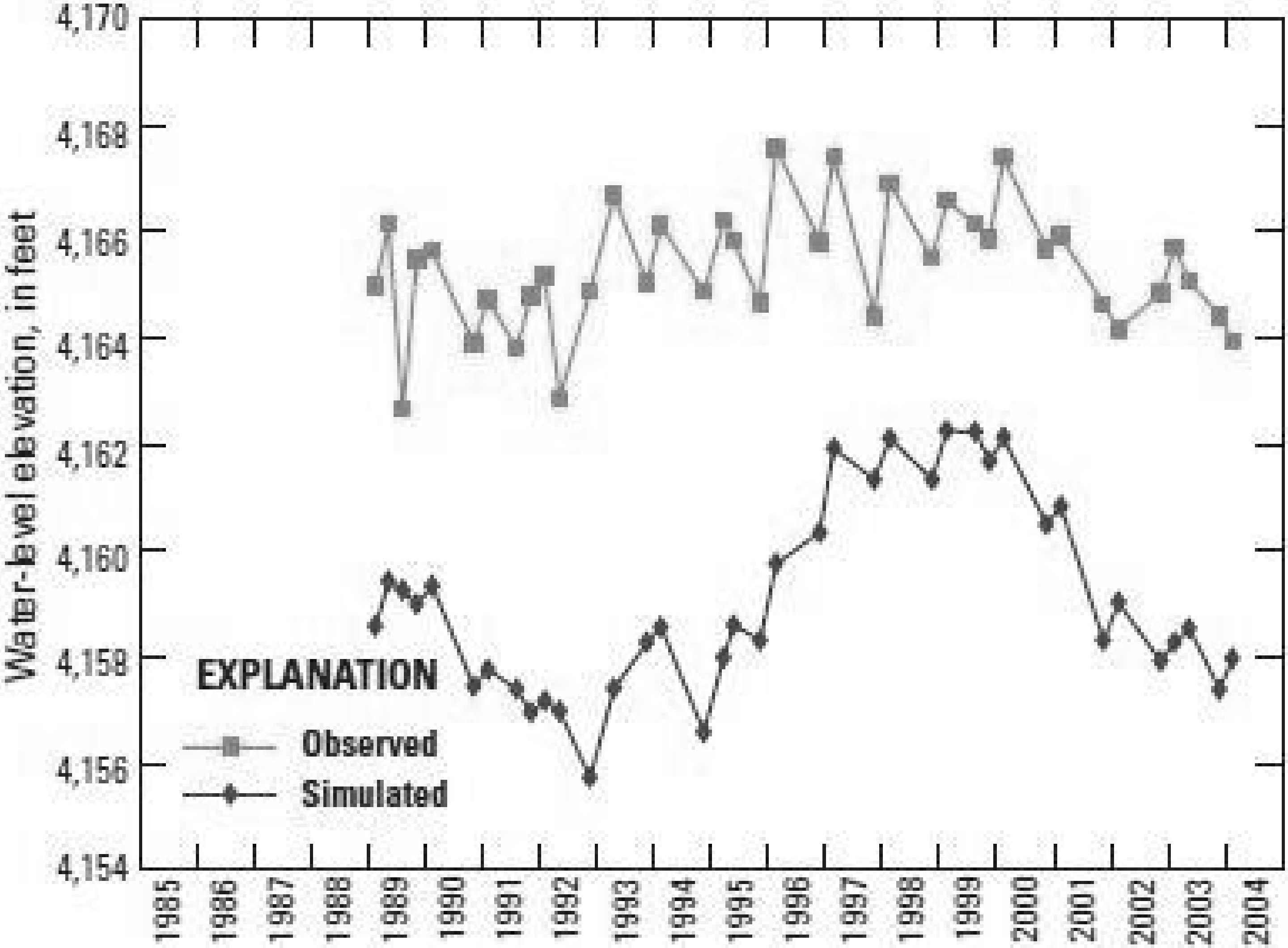

Figure 18. Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

17-01174_013491;17-01174_013491

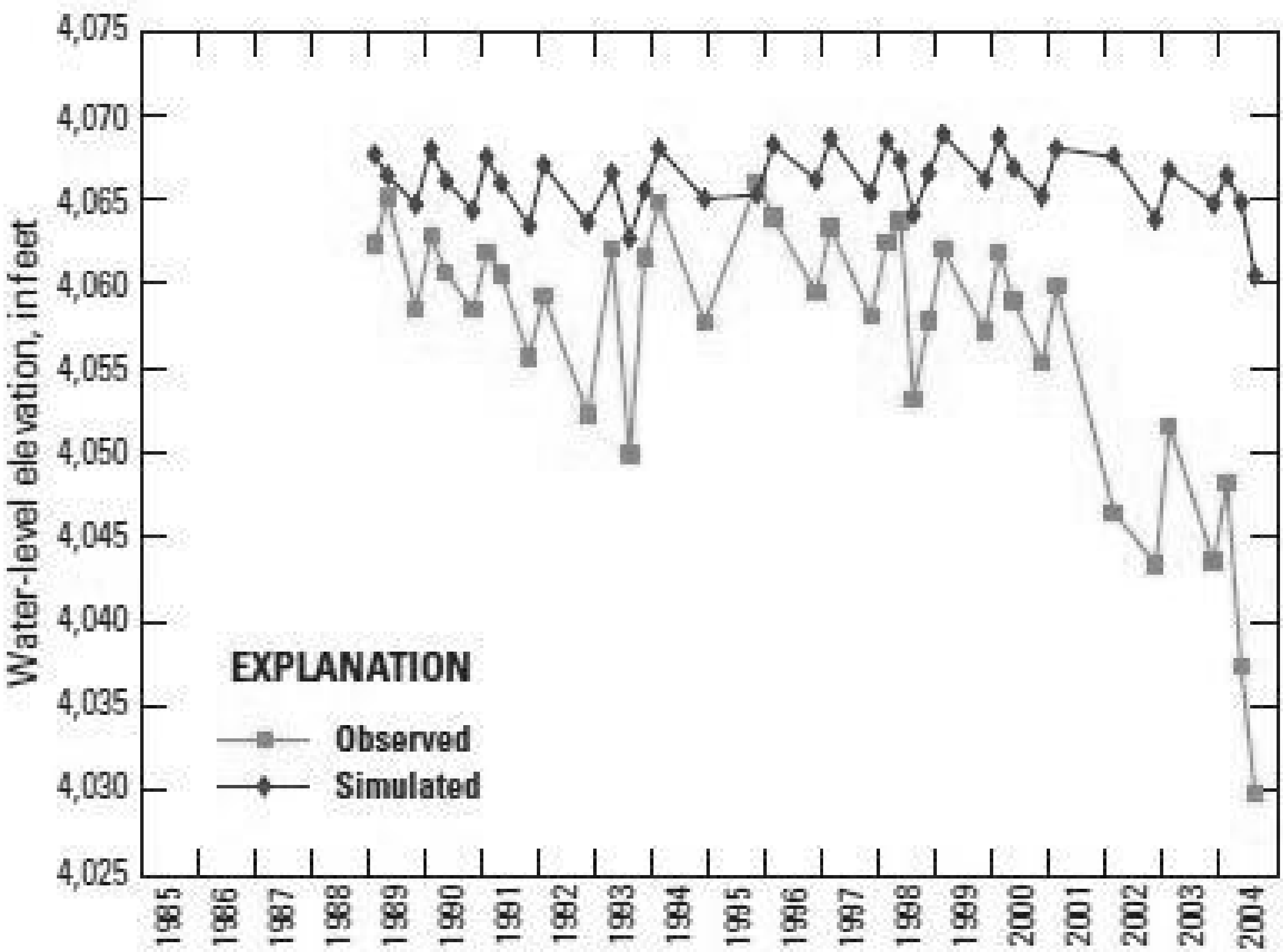

Figure 36. Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

17-01174_013492;17-01174_013492;17-01174_013493;17-01174_013494

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Nichols, Ryan
Sent: 2017-06-22T17:49:54-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-22T17:56:53-04:00

I spoke to Acting Assistant Secretary Scott Cameron about your recommendations this afternoon. Next I'll reach out to set up a meeting with you and Alan Mikkelsen as soon as he returns (probably right after July 4th). Then we can get things moving with Reclamation. Thanks for your work on this,

On Thu, Jun 22, 2017 at 4:32 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Attached is the material I sent to Amanda last month. Also, the uncertainty language as originally drafted by Amanda is in the following thread in **bold**.
---------- Forwarded message ----------
From: **Goklany, Indur** <indur_goklany@ios.doi.gov>
Date: Thu, May 25, 2017 at 11:20 AM
Subject: Re: Climate discussion
To: "Erath, Amanda" <aerath@usbr.gov>
Cc: David Raff <draff@usbr.gov>, Marketa Elsner <mmcguire@usbr.gov>, Avra Morgan <aomorgan@usbr.gov>, "Dahm, Katharine" <kdahm@usbr.gov>, Arlan Nickel <anickel@usbr.gov>

Amanda,
Attached are my comments/edits to Chapter 3.9 of the main report and suggestions for the uncertainty discussion in the Summary Report.

I also received a copy of the Niobrara Report (only the Summary and appendices). But my suggestion is let's do one at a time. Once we have wrestled with the Klamath report, it should be easier to address that.

Thanks, and best regards.

Goks

On Thu, May 18, 2017 at 5:05 PM, Erath, Amanda <aerath@usbr.gov> wrote:

Hello Goks,
Below is the uncertainty language that we have drafted to be added to the Klamath River Basin Study Summary Report. I have also attached the Klamath River Basin Study Full Report. Sorry for the oversight in not sending the Full Report to you. The Full Report includes uncertainty discussions near the end of chapters 3, 4, 5, and 6 (identified in the table of contents for each chapter). [redacted] (b)(5) Please let me know if you

have any questions.

[redacted]

Amanda Erath
Program Analyst
Policy and Administration
Denver Federal Center
Building 67 (84-51000)
P.O. Box 25007
Denver, CO 80225-0007

Office: (303) 445-2766
Email: aerath@usbr.gov

On Fri, May 12, 2017 at 8:55 AM, David Raff <draff@usbr.gov> wrote:

Thanks. We'll read as well and incorporate into our uncertainty language as appropriate.

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:

The attached sheet has the citations I was refering to regarding the modeled rate of warming vs. observed rates. [redacted]

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted]

[redacted]

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

--
Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

17-01174_013495;17-01174_013495;17-01174_013496;17-01174_013497

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-06-23T07:58:00-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-23T07:58:26-04:00

Thanks Ryan. It was a pleasure to sit down with you.

On Thu, Jun 22, 2017 at 5:49 PM, Nichols, Ryan <ryan_nichols@ios.doi.gov> wrote:

> I spoke to Acting Assistant Secretary Scott Cameron about your recommendations this afternoon. Next I'll reach out to set up a meeting with you and Alan Mikkelsen as soon as he returns (probably right after July 4th). Then we can get things moving with Reclamation. Thanks for your work on this,

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Date: Thu, May 25, 2017 at 11:20 AM
Subject: Re: Climate discussion
To: "Erath, Amanda" <aerath@usbr.gov>
Cc: David Raff <draff@usbr.gov>, Marketa Elsner <mmcguire@usbr.gov>, Avra Morgan <aomorgan@usbr.gov>, "Dahm, Katharine" <kdahm@usbr.gov>, Arlan Nickel <anickel@usbr.gov>

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Thanks, and best regards.

Goks

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[redacted] (b)(5)

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[redacted] (b)(5)

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Good Afternoon Again Goks,

[redacted] (b)(5)

17-01174_013495;17-01174_013495;17-01174_013496;17-01174_013497

[redacted]

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

--
Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

To: David Raff[draff@usbr.gov]
Cc: Dean Marrone[dmarrone@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Amanda Erath[aerath@usbr.gov]
From: Goklany, Indur
Sent: 2017-06-23T09:38:23-04:00
Importance: Normal
Subject: Re: Climate discussion
Received: 2017-06-23T09:38:50-04:00

Thanks for the update.

[redacted]

On Thu, Jun 22, 2017 at 10:33 AM, David Raff <draff@usbr.gov> wrote:

Good Morning Goks,

Thank you for your continued interest and attention to Reclamation's Basin Studies. We certainly appreciate the priority you are giving to the Klamath study.

Our Acting Commissioner, Mr. Alan Mikkelsen, is engaged to help identify the path forward he would like to take to meet the needs and expectations of our cost share partners as well as the administration.

As soon as we receive additional guidance we will address your previous comments as appropriate and circle back with you. I do not have a firm timeframe to provide to you but certainly hope it will be in the next few weeks. Thank you again and hope you are enjoying the start to summer.

Best Regards,
Dave

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From: **Goklany, Indur** <indur_goklany@ios.doi.gov>
Date: Thu, Jun 22, 2017 at 7:49 AM
Subject: Re: Climate discussion
To: "Erath, Amanda" <aerath@usbr.gov>

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On Wed, Jun 21, 2017 at 10:20 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

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[redacted] (b)(5)

[redacted] (b)(5)

Amanda Erath
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Policy and Administration
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David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer |
Department of the Interior Bureau of Reclamation | 1849 C Street
NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

17-01174_013502;17-01174_013502;17-01174_013503;17-01174_013504;17-01174_013505

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-06-23T09:38:58-04:00
Importance: Normal
Subject: Fwd: Climate discussion
Received: 2017-06-23T09:39:24-04:00

FYI
---------- Forwarded message ----------
From: **Goklany, Indur** <indur_goklany@ios.doi.gov>
Date: Fri, Jun 23, 2017 at 9:38 AM
Subject: Re: Climate discussion
To: David Raff <draff@usbr.gov>
Cc: Dean Marrone <dmarrone@usbr.gov>, Avra Morgan <aomorgan@usbr.gov>, Amanda Erath <aerath@usbr.gov>

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[redacted] (b)(5)

17-01174_013502;17-01174_013502;17-01174_013503;17-01174_013504;17-01174_013505

[redacted] (b)(5)

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To: Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
From: Linford, Brooke
Sent: 2017-07-03T08:31:44-04:00
Importance: Normal
Subject: EKIP Redemption Report for 9/1/2016 - 6/30/2017
Received: 2017-07-03T08:32:17-04:00
EKIP Redemption Data 9-1-2016 - 6-30-2017.xlsx

Hello everyone,
The issuance of Every Kid in a Park 4th Grade Passes continues to be strong. Attached is the latest report.

Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1849 C Street, NW
Room 2345
Washington, DC 20240

Phone: 202-513-7139

Every Kid in a Park 4th Grade Pass

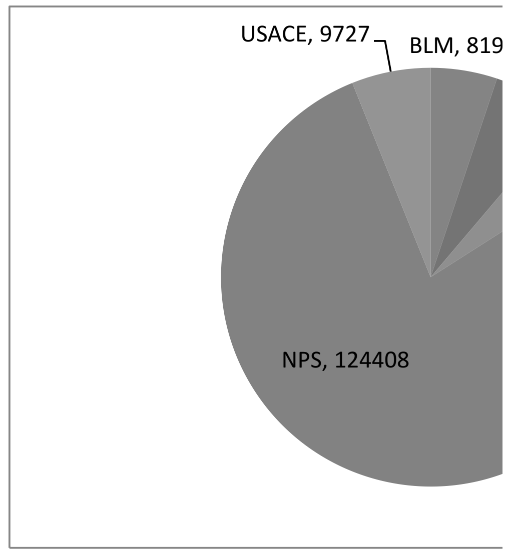
Reported in Redemption Site 9/1/2016 - 6/30/2017

FOR INTERNAL USE ONLY

Grand Total **159,617**

BLM	**8,190**
Red Rock Canyon National Conservation Area BLM	1,428
California BLM Office	1,250
National Historic Trails Interpretive Center	755
Idaho State Office - BLM	619
Red Rock Canyon National Conservation Area - BLM	549
BLM Eastern States Office	439
Colorado BLM Office	368
Eagle Lake BLM Field Office	351
Eastern States BLM Field Office	297
BLM Prineville Office	248
Pompeys Pillar Interpretive Center - BLM	245
Klamath Falls Resource Area	207
Gunnison Gorge National Conservation Area	204
Idaho BLM Office	197
Redding BLM Field Office	192
Palm Springs - South Coast BLM Field Office	144
Ukiah BLM Field Office	134
Nevada BLM Office	102
Alturas BLM Field Office	99
Coos Bay BLM District Office	69
Rio Puerco BLM Field Office	59
Casper Field Office - BLM	58
Arizona Strip District Office (in Utah)	54
BLM Medford Office	54
Miles City BLM Office	13
Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument)	13
Yaquina Head Oustanding Natural Area	11
Spokane BLM Office	9
Royal Gorge BLM Field Office	4
Utah BLM Office	4
Grand Junction BLM Field Office	3
Richfield BLM Field Office	2
Las Vegas BLM Field Office	2
Arizona BLM State Office	2
Wyoming BLM Office	2
Eugene District BLM Office	1

5.1%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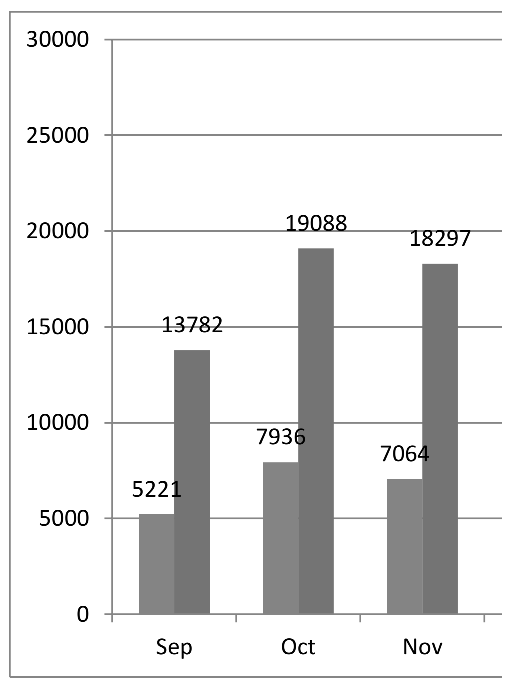
NPS, 124408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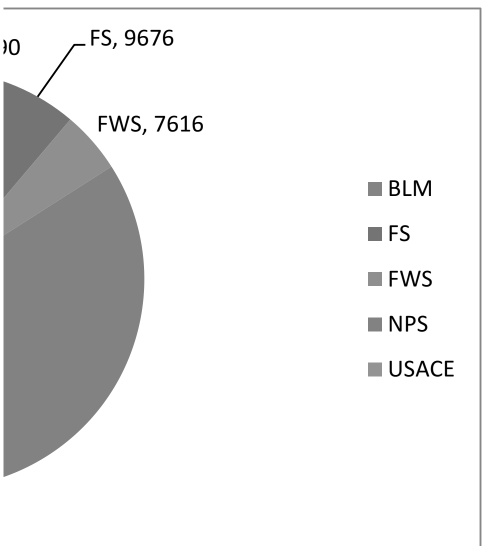
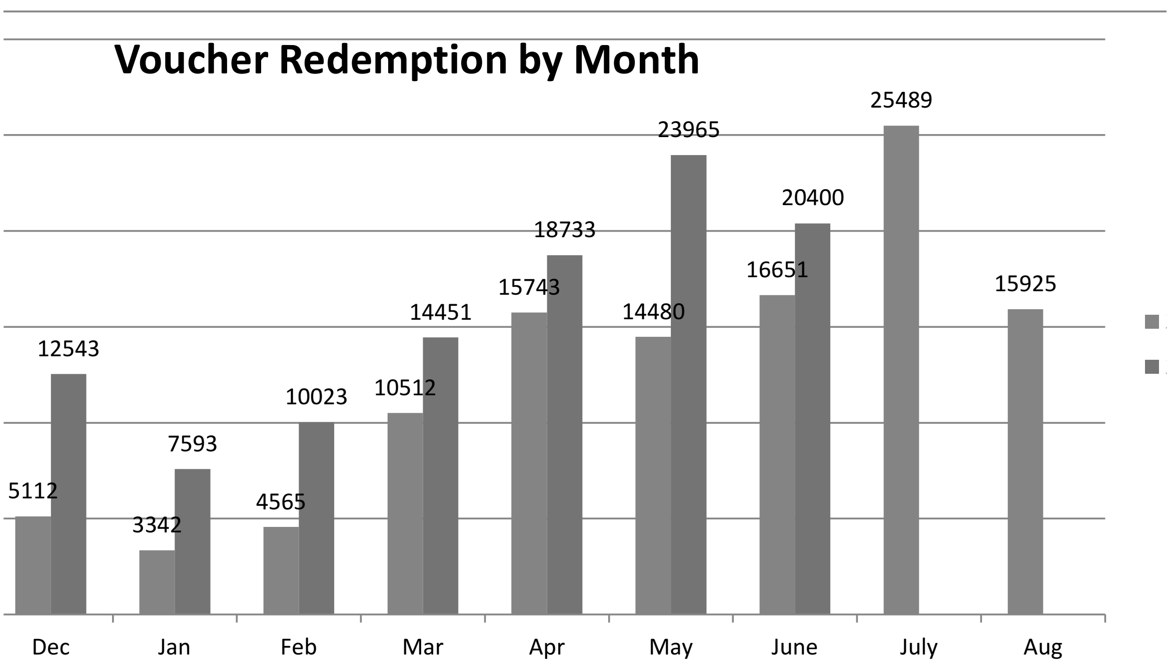
Oct
Nov

17-01174_013507;17-01174_013507;17-01174_013508;17-01174_013509;17-01174_013510;17-01174_013511;1...





2015/2016

2016/2017

Kremmling BLM Field Office	1
Rock Springs Field Office - BLM	1
FS	**9,676**
Land Between the Lakes	767
Apache-Sitgreaves NF - Lakeside District	734
Stanislaus NF - Mi-Wok District	500
US Forest Service Region 9	407
Chugach National Forest	404
Lincoln NF - Sacramento District	397
Rogue River - Siskiyou NF - Main Office	368
Okanogan-Wenatchee NF - Cle Elum District	363
Lewis & Clark NF - Main Office	361
Umpqua NF - Main Office	340
Caribou-Targhee NF - Ashton/Island Park District	298
Cibola NF - Main Office	292
Fremont-Winema NF - Main Office	247
US Forest Service Regional Office	238
Ottawa NF - Visitor Center	226
Uinta-Wasatch-Cache NF - Pleasant Grove District	182
Umpqua NF - Diamond Lake Visitor Center	181
Mt Hood NF - Hood River District	177
White Mountain NF - Main Office	169
San Bernardino NF - Mountaintop District - Big Bear Ranger Station	149
Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District	111
Ocala NF - Lake George District	110
Apache-Sitgreaves NF - Springerville District	109
Bighorn NF - Powder River District	109
Apache-Sitgreaves NF - Alpine District	109
Caribou-Targhee NF - Dubois District	107
Coconino NF - Red Rock Visitor's Center	103
Pike & San Isabel NF - South Platte District	99
Olympic NF - Main Office	94
Shawnee NF - Mississippi Bluffs District	90
Eldorado NF - Main Office	89
Tongass NF - Mendenhall Glacier Visitor's Center	88
Allegheny NF - Bradford District	88
Carson NF - Main Office	71
Coconino NF - Red Rock District	68
Malheur NF - Emigrant Creek District	67
Okanogan-Wenatchee NF - Tonasket District	60
Clearwater NF - Main Office	55
Mt Hood NF - Zigzag District	54
Umpqua NF - North Umpqua District	51
Outdoor Recreation Information Center - Seattle Flagship REI Store	48
Chequamegon-Nicolet NF - Main Office	44

6.1%

17-01174_013507;17-01174_013507;17-01174_013508;17-01174_013509;17-01174_013510;17-01174_013511;1...

17-01174_013507;17-01174_013507;17-01174_013508;17-01174_013509;17-01174_013510;17-01174_013511;1...

Colville NF - Republic District	40
Coronado NF - Main Office	36
Bighorn NF - Main Office	34
Uinta-Wasatch-Cache NF - American Fork Fee Station	33
Mt Baker/Snoqualmie NF - Snoqualmie District	29
Shasta-Trinity NF - Main Office	28
Black Hills NF - Mystic District	28
Gifford Pinchot NF - Mt Adams District	27
San Bernardino NF - Front Country District - Cajon Ranger Station	26
Humboldt-Toiyabe NF - Bridgeport District	24
Apache-Sitgreaves NF - Supervisor's Office	24
Tonto NF - Main Office	23
Uinta-Wasatch-Cache NF - Heber-Kamas District	22
Tonto NF - Mesa District	22
Prescott NF - Bradshaw District	20
Washington & Jefferson NF - Lee District	20
Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District	20
Arapahoe & Roosevelt NF - Clear Creek District	19
Sequoia NF - Main Office	17
Sequoia NF - Kern River District - Lake Isabella Office	17
San Bernardino NF - Main Office	17
Carson NF - El Rito Station	17
Deschutes NF - Bend/Fort Rock District	17
Fishlake NF - Fillmore District	17
Kaibab NF - North Kaibab District	15
Humboldt-Toiyabe NF - Main Office	15
Bridger-Teton NF - Pinedale District	14
Manti-La Sal NF - Sanpete District	14
Sawtooth NF - Fairfield District	13
Gifford Pinchot NF - Main Office	13
Tonto NF - Cave Creek District	12
Caribou-Targhee NF - Westside District	12
Mt Baker/Snoqualmie NF - Enumclaw Office	12
Apache-Sitgreaves NF - Black Mesa District	11
Santa Fe NF - Main Office	11
Tongass NF - Southeast Alaska Discovery Center	10
Coconino NF - Main Office	10
Idaho Panhandle NF - Coeur d'Alene River District	10
Black Hills NF - Main Office	9
Pike & San Isabel NF - Salida District	9
Siuslaw NF - Main Office	9
Sawtooth NF - Main Office	9
Manti-La Sal NF - Main Office	8
Six Rivers NF - Mad River District	8
Fishlake NF - Main Office	8

17-01174_013507;17-01174_013507;17-01174_013508;17-01174_013509;17-01174_013510;17-01174_013511;1...

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17-01174_013507;17-01174_013507;17-01174_013508;17-01174_013509;17-01174_013510;17-01174_013511;1...

Coronado NF - Santa Catalina District	8
Olympic NF - Pacific District	8
Kaibab NF - Williams District	7
Bighorn NF - Medicine Wheel/Paintrock District	6
Flathead NF - Tally Lake District	6
Sawtooth NF - Minidoka District	6
Fishlake NF - Fremont River District	6
Coconino NF - Mogollon Rim District	6
Nebraska National Forest - Pine Ridge District	5
White River NF - Dillon District	5
Umatilla NF - Walla Walla District	5
San Bernardino NF - San Jacinto District	5
Arapahoe & Roosevelt NF - Boulder District	5
Kaibab NF - Main Office	5
Cleveland NF - Trabuco District	5
Arapahoe & Roosevelt NF - Canyon Lakes District	5
Colville NF - Newport District	4
Willamette NF - McKenzie River District	4
Uinta-Wasatch-Cache NF - Evanston District	4
Caribou-Targhee NF - Palisades District	4
Prescott NF - Chino District	4
Rogue River - Siskiyou NF - Powers District	3
Malheur NF - Main Office	3
Arapahoe & Roosevelt NF - Sulphur District	3
Humboldt-Toiyabe NF - Carson District	3
Payette NF - McCall District	3
Inyo NF - Mammoth Lakes Center	3
Okanogan-Wenatchee NF - Main Office	3
Crooked River National Grasland	3
Klamath NF - Main Office	3
Green Mountain NF - Middlebury Station	3
Klamath NF - Scott River & Salmon River Districts	3
Mt Hood NF - Clackamas River District	3
Okanogan-Wenatchee NF - Entiat District	3
Angeles NF - Main Office	3
Rogue River - Siskiyou NF - Wild Rivers District	3
Hoosier National Forest	2
Nez Perce NF - Main Office	2
Okanogan-Wenatchee NF -Wenatchee River District	2
Helena NF - Helena District	2
San Juan NF - Dolores District	2
Idaho Panhandle NF - Main Office	2
Rogue River - Siskiyou NF - High Cascades District	2
Fishlake NF - Beaver District	2
San Bernardino NF - Front Country District - San Gorgonio Ranger Station	2

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Sawtooth NF - Ketchum District	2
Uinta-Wasatch-Cache NF - Logan District	2
Black Hills NF - Bearlodge District	2
Beaverhead-Deerlodge NF - Main Office	2
Willamette NF - Detroit District	2
Caribou-Targhee NF - Montpelier District	2
White Mountain NF - Saco District	2
Rogue River - Siskiyou NF - Gold Beach District	2
Helena NF - Lincoln District	2
Shasta-Trinity NF - Shasta Lake Station	2
Coronado NF - Douglas District	2
Angeles NF - San Gabriel River District	1
Okanogan-Wenatchee NF - Naches District	1
Ashley NF - Flaming Gorge District	1
Sawtooth NF - Stanley District	1
Siuslaw NF - Waldport Office	1
Grand Mesa, Uncompahgre, & Gunnison NF	1
San Juan Public Lands Center - FS	1
Green Mountain NF - Main Office	1
Sierra NF - Oakhurst Office	1
Colville NF - Three Rivers District	1
Tahoe NF - Main Office	1
Croatan NF - Main Office	1
Lincoln NF - Guadalupe District	1
Mt Baker/Snoqualmie NF - Mt Baker District	1
Ashley NF - Duchesne District	1
Grey Towers National Historic Site	1
Ozark - St. Francis NF - Sylamore Mountain District	1
Gallatin NF - Hebgen Lake District	1
Shasta-Trinity NF - Mount Shasta Station	1
Gifford Pinchot NF - Cowlitz Valley District	1
Six Rivers NF - Orleans District	1
Kaibab NF - Tusayan District	1
Los Padres NF - Main Office	1
Mendocino NF - Main Office	1
Shasta-Trinity NF - Weaverville Station	1
Rogue River - Siskiyou NF - Siskiyou Mountains District	1
Idaho Panhandle NF - St. Joe District	1
Ozark - St. Francis NF - Boston Mountain District	1
Mendocino NF - Upper Lake District	1
Rio Grande NF - Conejos Peak District	1
Routt NF - Hahans Peak/Bears Ears District	1
Umatilla NF - Main Office	1
Dakota Prairie Grasslands - Medora District	1
Umpqua NF - Cottage Grove District	1

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Nantahala NF - Highlands District	1
Wallowa-Whitman NF - Main Office	1
Rio Grande NF - Divide District	1
Payette NF - New Meadows District	1
Sierra NF - Main Office	1
Routt NF - Parks Walden District	1
Sierra NF - High Sierra District	1
Sam Houston NF	1
Black Hills NF - Hell Canyon District	1
San Juan NF - Pagosa District	1
Huron-Manistee NF - Cadillac/Manistee District	1
FWS	**7,616**
J.N. "Ding" Darling National Wildlife Refuge	3,131
Arthur R. Marshall Loxahatchee NWR	1,347
Nisqually NWR	717
Two Rivers National Wildlife Refuge	415
Sam D. Hamilton Noxubee NWR	392
Hobe Sound NWR Nature Center (also sold at fee booth)	350
Back Bay NWR	325
Bombay Hook National Wildlife Refuge	217
St. Marks National Wildlife Refuge	163
Assabet River NWR	106
Okefenokee NWR	105
Chincoteague NWR	90
Merritt Island National Wildlife Refuge	83
DeSoto National Wildlife Refuge	69
Sacramento NWR	37
National Elk Refuge	20
Fish and Wildlife Service Regional Office	18
Don Edwards San Francisco Bay NWR	9
Parker River National Wildlife Refuge	6
Long Island NWR Complex	4
Rocky Mountain Arsenal NWR	3
Ottawa National Wildlife Refuge	3
Bosque del Apache NWR	3
Deer Flat NWR	2
Ridgefield NWRC	1
NPS	**124,408**
San Juan National Historic Site	7,816
Assateague Island National Seashore	5,060
Fort McHenry National Monument	4,532
Hopewell Culture National Historical Park	4,500
Yosemite National Park	4,281
Lake Mead National Recreation Area	4,264

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Colonial National Historical Park	4,107
Cuyahoga Valley National Park	3,752
Grand Canyon National Park	3,652
Zion National Park	3,649
Channel Islands National Park	3,363
Great Falls Park	3,323
Chesapeake & Ohio Canal NHP	2,946
Indiana Dunes National Lakeshore	2,833
Garfield National Historic Site	2,544
Yellowstone National Park	2,348
Chamizal National Memorial	2,251
Mount Rainier National Park	2,041
Rocky Mountain National Park	2,034
Arches National Park	1,998
Joshua Tree National Park	1,987
Acadia National Park	1,797
Lewis & Clark National Historical Park	1,635
Badlands National Park	1,617
Tumacacori National Historical Park	1,254
San Francisco Maritime National Historical Park	1,194
Pictured Rocks National Seashore	1,181
Fort Vancouver National Historic Site	1,146
Bents Old Fort Historic Site	1,107
Delaware Water Gap National Rec Area	1,098
Richmond National Battlefield Park	1,081
Pinnacles National Monument	1,078
Petroglyph National Monument	1,037
Harpers Ferry National Historical Park	1,031
Walnut Canyon National Monument	1,013
Sequoia & Kings Canyon National Park	986
Lowell National Historical Park	964
Catoctin Mountain Park	960
Bryce Canyon National Park	938
Golden Gate NRA - Muir Woods Visitors Ctr	925
Amistad National Recreation Area	864
Grand Teton National Park	860
Death Valley National Park	842
Crater Lake National Park	818
Petrified Forest National Park	793
Montezuma Castle National Monument	763
Cedar Breaks National Monument	743
Colorado National Monument	715
Sleeping Bear Dunes National Lakeshore	708
Blue Ridge Parkway (Campgrounds)	688
Cumberland Island National Seashore	685

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Big Thicket National Preserve	651
Pu'uhonua O Honaunau	638
Cabrillo National Monument	545
Mesa Verde National Park	539
Casa Grande Ruins National Monument	537
Carlsbad Caverns National Park	529
Wright Brothers National Memorial	522
Hawaii Volcanoes National Park	519
Olympic National Park	497
Everglades National Park	488
Castillo de San Marcos National Monument	472
Organ Pipe Cactus National Monument	466
Little Rock Central High School NHS	464
Canyonlands National Park	453
Guadalupe Mountains National Park	423
Capulin Volcano National Monument	422
Dinosaur National Monument (Passes only sold at UT location))	418
Tonto National Monument	402
Appomattox Court House Historical Park	400
Big South Fork National River & Recreation Area	376
Glacier National Park	357
Shenandoah National Park - Thornton Gap Entrance	347
Padre Island National Seashore	344
Shenandoah National Park - Front Royal Entrance	320
Shenandoah National Park - Rockfish Entrance	302
Chaco Culture National Historical Park	287
Lava Beds National Monument	285
Devils Tower National Monument	280
Edison National Historical Park	276
Shenandoah National Park - Swift Run Entrance	261
Gila Cliff Dwellings National Monument	257
Golden Spike National Historic Site	253
National Historic Oregon Trail Interpretive Center	252
Saguaro National Park	245
Florissant Fossil Beds National Monument	234
Ulysses S Grant National Historic Site	232
Bighorn Canyon National Recreation Area	216
Cape Cod National Seashore - Provincelands V.C.	210
Hot Springs National Park	209
Great Sand Dunes National Park	208
Chickamauga & Chattanooga National Military Park	203
Obed Wild and Scenic River	192
Capitol Reef National Park	189
Fort Washington Park	180
Haleakala National Park	177

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Big Bend National Park	176
Craters of the Moon National Monument	167
Fossil Butte National Monument	164
White Sands National Monument	158
Lassen Volcanic National Park	157
Glen Canyon NRA	148
Weir Farm National Historic Site	143
Gulf Islands National Seashore	140
Aztec Ruins National Monument	139
William Howard Taft National Historical Site	135
Mammoth Cave National Park	130
Fort Smith National Historic Site	129
Sunset Crater Volcano National Monument	126
Jewel Cave National Monument	120
Brown v Board of Education National Historic Site	119
Antietam National Battlefield	115
Bandalier National Monument	106
Alcatraz Island (see Golden Gate NRA)	103
Whiskeytown National Recreation Area	102
Scotts Bluff National Monument	100
Greenbelt Park	98
Prince William Forest Park	97
Saint Gaudens National Historic Site	95
Coronado National Monument	93
Theodore Roosevelt National Park - South Unit	88
Timpanogos Cave National Monument	87
Canaveral National Seashore	84
Mount Rushmore National Memorial	65
Rainbow Bridge National Monument (see Glen Canyon, UT)	61
Klondike Gold Rush National Historical Park	60
Cape Cod National Seashore - Salt Pond V.C.	58
Steamtown National Historic Site	56
Lewis & Clark NHT/NPS Midwest Regional Office	53
Point Reyes National Seashore	50
Denali National Park & Preserve	49
Chickasaw National Recreation Area	48
Little Bighorn Battlefield National Monument	45
Pipestone National Monument	43
Wind Cave National Park	40
Wilson's Creek National Battlefield	39
Fort Moultrie National Monument	37
Fort Davis National Historic Site	36
Fort Union National Monument	35
Tuzigoot National Monument	34
Great Basin National Park	34

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Wupatki National Monument	33
Lincoln Boyhood National Memorial	31
Harry S Truman National Historic Site	31
Apostle Islands National Lakeshore	27
Vicksburg National Military Park	27
Saratoga National Historical Park	20
Pipe Spring National Monument	18
Gateway National Recreation Area - Sandy Hook	16
Natural Bridges National Monument	16
Mississippi National River & Recreation Area	16
Redwood National Park	15
Chickamauga and Chattanooga NMP- Lookout Mountain	15
Black Canyon of the Gunnison	14
Great Smoky Mountains NP - Sugarland VC	12
Theodore Roosevelt National Park - North Unit	12
Great Smoky Mountains NP - Oconaluftee Visitor's Center	10
Biscayne National Park	10
Alaska Public Lands Visitor Center - Anchorage	7
Johnstown Flood National Memorial	5
Herbert Hoover National Historical Site	5
Fort Necessity National Battlefield	4
Carl Sandburg Home National Historic Site	3
Valles Caldera National Preserve	3
Great Smoky Mountains NP - Smokemont Campground	3
Isle Royale National Park	3
Great Smoky Mountain NP - Cades Cove Campground	3
Homestead National Monument of America	2
Glen Canyon NRA (both AZ and UT)	2
Kings Mountain National Military Park	2
San Antonio Missions National Historic Park	1
Marsh-Billings-Rockefeller National Historical Park	1
USACE	**9,727**
Mississippi River Project	2,283
Philpott Lake	1,349
Allatoona	969
Falls Lake	692
Wappapello Lake	477
Table Rock Lake	413
Proctor lake	396
Lake Shelbyville	365
Gull Lake Recreation Area	360
Englebright Lake	318
Raystown Lake Project	245
Sam Rayburn Lake	235
Jordan Lake	195

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Sandy Lake Recreation Area	191
Carters	175
Woodruff-Seminole	150
W. Kerr Scott Dam and Reservoir	144
Bonneville Lock and Dam- Bradford Island Visitor Center	115
John H. Kerr Dam and Reservoir	112
Willamette Valley Project (Cottage Grove/Dorena)	77
Cordell Hull Lake	75
Greers Ferry Lake	60
Thurmond Project	50
Eastman Lake	50
Black Butte Lake	49
Cochiti Lake	49
Cottage Grove Lake - Pine Meadows Campground	38
Leech Lake Recreation Area	27
Gillham Lake	23
Mark Twain Lake	13
Taylorsville Lake	6
West Hill Dam	4
The Dalles Lock and Dam- Visitor Center	3
North Hartland Lake	2
Smithville Lake Project	2
Eau Galle Recreation Area	2
Clinton Lake Project	2
Tioga-Hammond Lakes Project	1
Shenango River Lake	1
Georgetown Lake	1
Hensley Lake	1
Abiquiu Lake	1
Barren River Lake	1
J. Percy Priest Lake	1
Coralville Lake	1
Bay Model Visitor Center	1
Cowanesque Lake Project	1
Success Lake	1

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To: Margo Harris[mrharris@usgs.gov]
From: Goklany, Indur
Sent: 2017-07-27T11:59:04-04:00
Importance: Normal
Subject: Fwd: Follow-up to today's 9:00 mtg
Received: 2017-07-27T11:59:45-04:00

Margo -- Here is the e-mail. [redacted] (b)(5) .Thanks -- Indur Goklany (Goks)
---------- Forwarded message ----------
From: **William Werkheiser** <whwerkhe@usgs.gov>
Date: Sun, Jul 23, 2017 at 9:54 AM
Subject: Re: Follow-up to today's 9:00 mtg
To: "Goklany, Indur" <indur_goklany@ios.doi.gov>
Cc: James Cason <james_cason@ios.doi.gov>

Thanks for reaching out Indur. It was good to meet you, too. I will have my assistant, Margo Harris set up a meeting with you, BOR, and USGS [redacted] (b)(5) -Best,
Bill

Sent from my iPad

> On Jul 21, 2017, at 3:33 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:
>
> It was good to say "hello" to you.
>
> Is there any one you want me to work with on the follow-up to today's meeting?
>
> Thanks.

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Harris, Margo
Sent: 2017-07-27T15:01:28-04:00
Importance: Normal
Subject: Re: Follow-up to today's 9:00 mtg
Received: 2017-07-27T15:01:38-04:00

Sir:
I spoke with Bill briefly (he had to leave in a hurry) [redacted] (b)(5) He did give me a list of names for the meeting; I will be sending out a doodle poll for availability.

Respectfully,

Margo Robinson-Harris
Staff Assistant to the Director

Office of the Director
United States Department of the Interior
U.S. Geological Survey
Office Phone: (703) 648-7411
iPhone: (703) 935-3181
Office Fax: (703) 648-4454

On Thu, Jul 27, 2017 at 11:59 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Margo -- Here is the e-mail. [redacted] (b)(5) Thanks -- Indur Goklany (Goks)
---------- Forwarded message ----------
From: **William Werkheiser** <whwerkhe@usgs.gov>
Date: Sun, Jul 23, 2017 at 9:54 AM
Subject: Re: Follow-up to today's 9:00 mtg
To: "Goklany, Indur" <indur_goklany@ios.doi.gov>
Cc: James Cason <james_cason@ios.doi.gov>

Thanks for reaching out Indur. It was good to meet you, too. I will have my assistant, Margo Harris set up a meeting with you, BOR, and USGS [redacted] (b)(5) -Best,
Bill

Sent from my iPad

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>
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>
> Is there any one you want me to work with on the follow-up to today's meeting?

>
> Thanks.

To: Harris, Margo[mrharris@usgs.gov]
From: Goklany, Indur
Sent: 2017-07-27T15:06:17-04:00
Importance: Normal
Subject: Re: Follow-up to today's 9:00 mtg
Received: 2017-07-27T15:06:47-04:00

Thanks!

On Thu, Jul 27, 2017 at 3:01 PM, Harris, Margo <mrharris@usgs.gov> wrote:

Sir:
I spoke with Bill briefly (he had to leave in a hurry) and [redacted] names for the meeting; I will be sending out a doodle poll for availability.

Respectfully,

Margo Robinson-Harris
Staff Assistant to the Director

Office of the Director
United States Department of the Interior
U.S. Geological Survey
Office Phone: (703) 648-7411
iPhone: (703) 935-3181
Office Fax: (703) 648-4454

On Thu, Jul 27, 2017 at 11:59 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Margo -- Here is the e-mail. [redacted] Thanks -- Indur Goklany (Goks)
---------- Forwarded message ----------
From: **William Werkheiser** <whwerkhe@usgs.gov>
Date: Sun, Jul 23, 2017 at 9:54 AM
Subject: Re: Follow-up to today's 9:00 mtg
To: "Goklany, Indur" <indur_goklany@ios.doi.gov>
Cc: James Cason <james_cason@ios.doi.gov>

Thanks for reaching out Indur. It was good to meet you, too. I will have my assistant, Margo Harris set up a meeting with you, BOR, and USGS to [redacted] -Best,
Bill

Sent from my iPad

> On Jul 21, 2017, at 3:33 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

>
> It was good to say "hello" to you.
>
> Is there any one you want me to work with on the follow-up to today's meeting?
>
> Thanks.

17-01174_013556;17-01174_013556

To: Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
From: Linford, Brooke
Sent: 2017-08-02T07:56:41-04:00
Importance: Normal
Subject: EKIP Redemption Report for 9/1/2016 - 7/31/2017
Received: 2017-08-02T07:57:14-04:00
EKIP Redemption Data 9-1-2016 - 7-31-2017.xlsx

Hello Everyone,
Attached is the EKIP Redemption Report for 9/1/2016 - 7/31/2017. The exchanges for the month of July 2017 were less than in 2016 which is the first time this has happened. It is possible that the uncertainty over the continuation of the program has had an effect, but this is only speculation. Now that we are committed to continuing the program for the 2017/2018 school year this may be reversed. Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1849 C Street, NW
Room 2345
Washington, DC 20240

Phone: 202-513-7139

Every Kid in a Park 4th Grade Pass

Reported in Redemption Site 9/1/2016 - 7/31/2017

FOR INTERNAL USE ONLY

Grand Total	**180,858**
BLM	**8,704**
Red Rock Canyon National Conservation Area BLM	1,429
California BLM Office	1,250
National Historic Trails Interpretive Center	756
BLM Eastern States Office	687
Idaho State Office - BLM	619
Colorado BLM Office	568
Red Rock Canyon National Conservation Area - BLM	549
Eagle Lake BLM Field Office	351
Eastern States BLM Field Office	297
Pompeys Pillar Interpretive Center - BLM	252
BLM Prineville Office	248
Klamath Falls Resource Area	207
Gunnison Gorge National Conservation Area	204
Idaho BLM Office	197
Redding BLM Field Office	192
Palm Springs - South Coast BLM Field Office	144
Ukiah BLM Field Office	134
Nevada BLM Office	102
Alturas BLM Field Office	99
Coos Bay BLM District Office	69
Yaquina Head Oustanding Natural Area	66
Rio Puerco BLM Field Office	59
Casper Field Office - BLM	58
Arizona Strip District Office (in Utah)	54
BLM Medford Office	54
Miles City BLM Office	13
Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument)	13
Spokane BLM Office	9
Royal Gorge BLM Field Office	4
Utah BLM Office	4
Grand Junction BLM Field Office	3
Rock Springs Field Office - BLM	3
Wyoming BLM Office	2
Arizona BLM State Office	2
Richfield BLM Field Office	2
Las Vegas BLM Field Office	2

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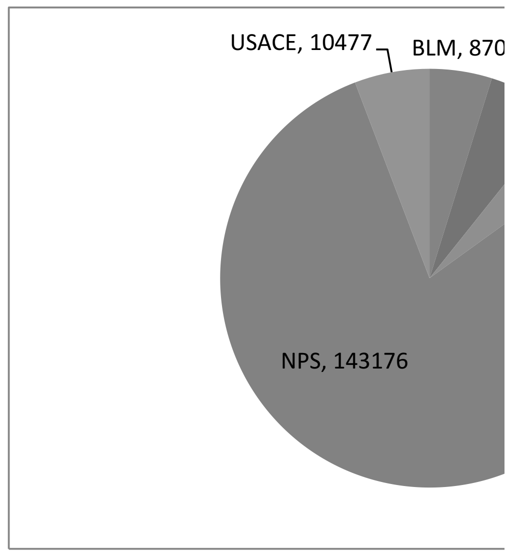
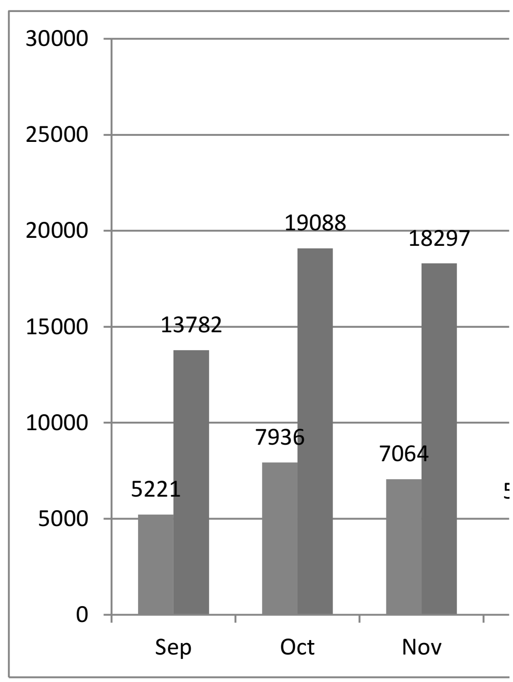


USACE, 10477
BLM, 870
NPS, 143176



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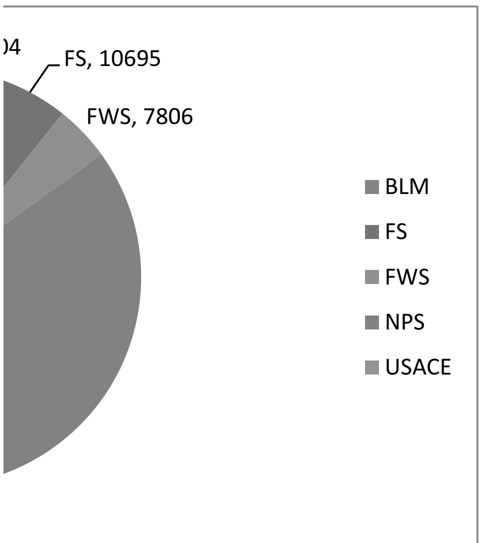

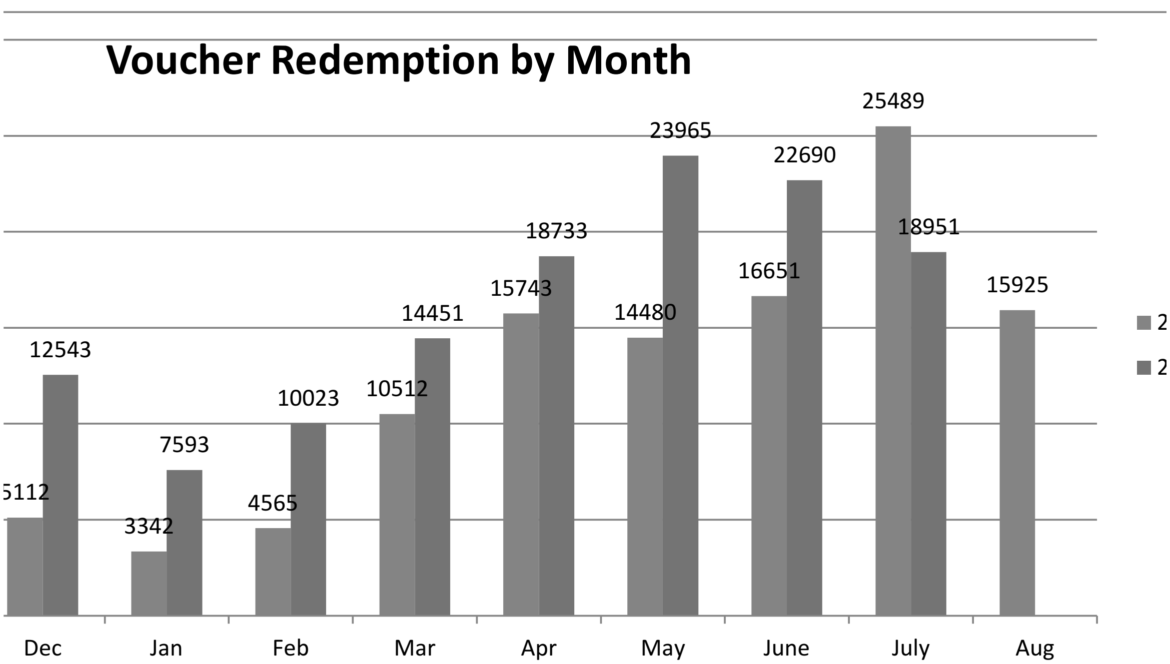

2015/2016
2016/2017

Kremmling BLM Field Office	1
Eugene District BLM Office	1
FS	**10,695**
Land Between the Lakes	807
Apache-Sitgreaves NF - Lakeside District	734
Stanislaus NF - Mi-Wok District	500
Lewis & Clark NF - Main Office	433
US Forest Service Region 9	407
Chugach National Forest	404
Lincoln NF - Sacramento District	397
Rogue River - Siskiyou NF - Main Office	368
Okanogan-Wenatchee NF - Cle Elum District	363
Umpqua NF - Main Office	340
Caribou-Targhee NF - Ashton/Island Park District	300
Cibola NF - Main Office	292
Mount St. Helens National Volcanic Monument	268
Fremont-Winema NF - Main Office	247
US Forest Service Regional Office	238
Ottawa NF - Visitor Center	226
Uinta-Wasatch-Cache NF - Pleasant Grove District	211
Umpqua NF - Diamond Lake Visitor Center	181
Mt Hood NF - Hood River District	177
San Bernardino NF - Mountaintop District - Big Bear Ranger Station	170
White Mountain NF - Main Office	169
Tongass NF - Southeast Alaska Discovery Center	154
Gifford Pinchot NF - Main Office	118
Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District	111
Ocala NF - Lake George District	110
Coconino NF - Red Rock Visitor's Center	110
Apache-Sitgreaves NF - Springerville District	109
Bighorn NF - Powder River District	109
Mt Hood NF - Zigzag District	109
Apache-Sitgreaves NF - Alpine District	109
Caribou-Targhee NF - Dubois District	107
Pike & San Isabel NF - South Platte District	101
Olympic NF - Main Office	94
Shawnee NF - Mississippi Bluffs District	91
Eldorado NF - Main Office	89
Allegheny NF - Bradford District	88
Tongass NF - Mendenhall Glacier Visitor's Center	88
Coconino NF - Red Rock District	81
Tahoe NF - Main Office	80
Carson NF - Main Office	71
Malheur NF - Emigrant Creek District	67
Okanogan-Wenatchee NF - Tonasket District	60

5.9%

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San Bernardino NF - Front Country District - Cajon Ranger Station	58
San Bernardino NF - Main Office	58
Outdoor Recreation Information Center - Seattle Flagship REI Store	56
Clearwater NF - Main Office	55
White River NF - Blanco District	51
Umpqua NF - North Umpqua District	51
Chequamegon-Nicolet NF - Main Office	44
Colville NF - Republic District	40
Coronado NF - Main Office	39
Bighorn NF - Main Office	37
Uinta-Wasatch-Cache NF - American Fork Fee Station	33
Apache-Sitgreaves NF - Supervisor's Office	32
Mt Baker/Snoqualmie NF - Snoqualmie District	31
Arapahoe & Roosevelt NF - Clear Creek District	30
Shasta-Trinity NF - Main Office	29
Black Hills NF - Mystic District	28
Gifford Pinchot NF - Mt Adams District	27
Humboldt-Toiyabe NF - Bridgeport District	24
Tonto NF - Mesa District	23
Tonto NF - Main Office	23
Uinta-Wasatch-Cache NF - Heber-Kamas District	22
Prescott NF - Bradshaw District	20
Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District	20
Washington & Jefferson NF - Lee District	20
Sequoia NF - Main Office	20
Deschutes NF - Bend/Fort Rock District	17
Sequoia NF - Kern River District - Lake Isabella Office	17
Fishlake NF - Fillmore District	17
Carson NF - El Rito Station	17
Humboldt-Toiyabe NF - Main Office	15
Kaibab NF - North Kaibab District	15
Manti-La Sal NF - Sanpete District	14
Bridger-Teton NF - Pinedale District	14
Sawtooth NF - Fairfield District	13
Caribou-Targhee NF - Westside District	12
Tonto NF - Cave Creek District	12
Mt Baker/Snoqualmie NF - Enumclaw Office	12
Santa Fe NF - Main Office	11
Idaho Panhandle NF - Coeur d'Alene River District	11
Apache-Sitgreaves NF - Black Mesa District	11
Coconino NF - Main Office	10
Siuslaw NF - Main Office	9
Black Hills NF - Main Office	9
Sawtooth NF - Main Office	9
Pike & San Isabel NF - Salida District	9

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Olympic NF - Pacific District	8
Six Rivers NF - Mad River District	8
Flathead NF - Tally Lake District	8
Fishlake NF - Main Office	8
Coronado NF - Santa Catalina District	8
Manti-La Sal NF - Main Office	8
Arapahoe & Roosevelt NF - Boulder District	7
Kaibab NF - Williams District	7
Fishlake NF - Fremont River District	6
Sawtooth NF - Minidoka District	6
Bighorn NF - Medicine Wheel/Paintrock District	6
Coconino NF - Mogollon Rim District	6
San Bernardino NF - San Jacinto District	6
Arapahoe & Roosevelt NF - Canyon Lakes District	5
Nebraska National Forest - Pine Ridge District	5
Umatilla NF - Walla Walla District	5
Kaibab NF - Main Office	5
Cleveland NF - Trabuco District	5
White River NF - Dillon District	5
Prescott NF - Chino District	5
Uinta-Wasatch-Cache NF - Evanston District	4
Caribou-Targhee NF - Palisades District	4
Colville NF - Newport District	4
Willamette NF - McKenzie River District	4
Okanogan-Wenatchee NF - Main Office	3
Klamath NF - Main Office	3
Inyo NF - Mammoth Lakes Center	3
Caribou-Targhee NF - Montpelier District	3
Arapahoe & Roosevelt NF - Sulphur District	3
Okanogan-Wenatchee NF - Entiat District	3
Malheur NF - Main Office	3
Angeles NF - Main Office	3
Rogue River - Siskiyou NF - Wild Rivers District	3
Humboldt-Toiyabe NF - Carson District	3
Klamath NF - Scott River & Salmon River Districts	3
Crooked River National Grasland	3
Payette NF - McCall District	3
Green Mountain NF - Middlebury Station	3
Hoosier National Forest	3
Mt Hood NF - Clackamas River District	3
Rogue River - Siskiyou NF - Powers District	3
Dakota Prairie Grasslands - Medora District	2
San Juan NF - Dolores District	2
Helena NF - Helena District	2
Shasta-Trinity NF - Shasta Lake Station	2

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Coronado NF - Douglas District	2
Okanogan-Wenatchee NF -Wenatchee River District	2
Gifford Pinchot NF - Cowlitz Valley District	2
White Mountain NF - Saco District	2
San Bernardino NF - Front Country District - San Gorgonio Ranger Station	2
Uinta-Wasatch-Cache NF - Logan District	2
Routt NF - Parks Walden District	2
Black Hills NF - Bearlodge District	2
Fishlake NF - Beaver District	2
Willamette NF - Detroit District	2
Rogue River - Siskiyou NF - Gold Beach District	2
Nez Perce NF - Main Office	2
Sawtooth NF - Ketchum District	2
Helena NF - Lincoln District	2
Beaverhead-Deerlodge NF - Main Office	2
Rogue River - Siskiyou NF - High Cascades District	2
Idaho Panhandle NF - Main Office	2
Ozark - St. Francis NF - Sylamore Mountain District	1
Huron-Manistee NF - Cadillac/Manistee District	1
Medicine Bow NF - Main Office	1
Los Padres NF - Main Office	1
Ashley NF - Duchesne District	1
Mendocino NF - Main Office	1
Green Mountain NF - Main Office	1
Angeles NF - San Gabriel River District	1
Okanogan-Wenatchee NF - Naches District	1
Ashley NF - Flaming Gorge District	1
Sierra NF - Main Office	1
Sam Houston NF	1
Colville NF - Three Rivers District	1
Rogue River - Siskiyou NF - Siskiyou Mountains District	1
Ozark - St. Francis NF - Boston Mountain District	1
Black Hills NF - Hell Canyon District	1
Sierra NF - Oakhurst Office	1
San Juan NF - Pagosa District	1
Routt NF - Yampa District	1
Umatilla NF - Main Office	1
US Forest Service in Mississippi - Main Office	1
Umpqua NF - Cottage Grove District	1
Shasta-Trinity NF - Mount Shasta Station	1
Wallowa-Whitman NF - Main Office	1
Routt NF - Hahans Peak/Bears Ears District	1
Sawtooth NF - Stanley District	1
Six Rivers NF - Orleans District	1
Payette NF - New Meadows District	1

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Nantahala NF - Highlands District	1
Grand Mesa, Uncompahgre, & Gunnison NF	1
Rio Grande NF - Divide District	1
Idaho Panhandle NF - St. Joe District	1
Kaibab NF - Tusayan District	1
Lincoln NF - Guadalupe District	1
Sierra NF - High Sierra District	1
Mendocino NF - Upper Lake District	1
Rio Grande NF - Conejos Peak District	1
Grey Towers National Historic Site	1
Ozark - St. Francis NF - Main Ofiice	1
San Juan Public Lands Center - FS	1
Croatan NF - Main Office	1
Shasta-Trinity NF - Weaverville Station	1
Nebraska National Forest - Bessey District	1
Siuslaw NF - Waldport Office	1
Mt Baker/Snoqualmie NF - Mt Baker District	1
Gallatin NF - Hebgen Lake District	1
FWS	**7,806**
J.N. "Ding" Darling National Wildlife Refuge	3,132
Arthur R. Marshall Loxahatchee NWR	1,370
Nisqually NWR	845
Two Rivers National Wildlife Refuge	415
Sam D. Hamilton Noxubee NWR	392
Hobe Sound NWR Nature Center (also sold at fee booth)	350
Back Bay NWR	325
Bombay Hook National Wildlife Refuge	217
St. Marks National Wildlife Refuge	163
Chincoteague NWR	117
Assabet River NWR	106
Okefenokee NWR	105
Merritt Island National Wildlife Refuge	83
DeSoto National Wildlife Refuge	69
Sacramento NWR	37
National Elk Refuge	27
Fish and Wildlife Service Regional Office	18
Don Edwards San Francisco Bay NWR	9
Parker River National Wildlife Refuge	8
Long Island NWR Complex	4
Rocky Mountain Arsenal NWR	3
Ottawa National Wildlife Refuge	3
Bosque del Apache NWR	3
Deer Flat NWR	2
Ridgefield NWRC	1

4.3%

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Seney National Wildlife Refuge	1
Laguna Atascosa NWR	1
NPS	**143,176**
San Juan National Historic Site	7,816
Yosemite National Park	5,225
Assateague Island National Seashore	5,175
Fort McHenry National Monument	4,532
Grand Canyon National Park	4,523
Hopewell Culture National Historical Park	4,500
Zion National Park	4,386
Lake Mead National Recreation Area	4,324
Colonial National Historical Park	4,199
Yellowstone National Park	4,087
Cuyahoga Valley National Park	3,752
Channel Islands National Park	3,713
Great Falls Park	3,359
Badlands National Park	3,297
Rocky Mountain National Park	3,176
Chesapeake & Ohio Canal NHP	2,956
Indiana Dunes National Lakeshore	2,833
Garfield National Historic Site	2,564
Acadia National Park	2,552
Mount Rainier National Park	2,336
Chamizal National Memorial	2,257
Arches National Park	2,143
Joshua Tree National Park	1,992
Sequoia & Kings Canyon National Park	1,916
Lewis & Clark National Historical Park	1,872
Grand Teton National Park	1,830
Tumacacori National Historical Park	1,254
Bryce Canyon National Park	1,248
Delaware Water Gap National Rec Area	1,201
San Francisco Maritime National Historical Park	1,194
Pictured Rocks National Seashore	1,181
Golden Gate NRA - Muir Woods Visitors Ctr	1,159
Fort Vancouver National Historic Site	1,156
Pinnacles National Monument	1,115
Bents Old Fort Historic Site	1,110
Petroglyph National Monument	1,099
Glacier National Park	1,090
Richmond National Battlefield Park	1,081
Crater Lake National Park	1,075
Harpers Ferry National Historical Park	1,061
Lowell National Historical Park	1,045
Walnut Canyon National Monument	1,039

79.2%

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Petrified Forest National Park	1,033
Catoctin Mountain Park	960
Sleeping Bear Dunes National Lakeshore	906
Amistad National Recreation Area	864
Death Valley National Park	862
Colorado National Monument	857
Mesa Verde National Park	855
Appomattox Court House Historical Park	847
Montezuma Castle National Monument	799
Cedar Breaks National Monument	782
Olympic National Park	754
Blue Ridge Parkway (Campgrounds)	688
Cumberland Island National Seashore	685
Carlsbad Caverns National Park	680
Big Thicket National Preserve	652
Pu'uhonua O Honaunau	647
Wright Brothers National Memorial	617
Hawaii Volcanoes National Park	615
Cabrillo National Monument	589
Casa Grande Ruins National Monument	544
Castillo de San Marcos National Monument	544
Dinosaur National Monument (Passes only sold at UT location))	517
Little Rock Central High School NHS	517
Everglades National Park	508
Canyonlands National Park	504
Devils Tower National Monument	491
Ulysses S Grant National Historic Site	467
Organ Pipe Cactus National Monument	466
Great Sand Dunes National Park	436
Guadalupe Mountains National Park	423
Capulin Volcano National Monument	422
Tonto National Monument	403
Shenandoah National Park - Thornton Gap Entrance	402
Big South Fork National River & Recreation Area	377
Padre Island National Seashore	366
Shenandoah National Park - Front Royal Entrance	356
Golden Spike National Historic Site	337
Capitol Reef National Park	335
Shenandoah National Park - Rockfish Entrance	334
Joshua Tree National Park	325
Carl Sandburg Home National Historic Site	317
Shenandoah National Park - Swift Run Entrance	317
Lava Beds National Monument	311
Edison National Historical Park	304
Glen Canyon NRA	297

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Chaco Culture National Historical Park	287
Florissant Fossil Beds National Monument	277
National Historic Oregon Trail Interpretive Center	271
Gila Cliff Dwellings National Monument	262
Saguaro National Park	258
Theodore Roosevelt National Park - South Unit	249
Lassen Volcanic National Park	245
White Sands National Monument	239
Craters of the Moon National Monument	228
Bighorn Canyon National Recreation Area	219
Cape Cod National Seashore - Provincelands V.C.	210
Hot Springs National Park	209
Chickamauga & Chattanooga National Military Park	203
Haleakala National Park	202
Obed Wild and Scenic River	192
Big Bend National Park	189
Mammoth Cave National Park	185
Fort Washington Park	184
Gulf Islands National Seashore	166
Fossil Butte National Monument	164
Klondike Gold Rush National Historical Park	163
Sunset Crater Volcano National Monument	149
Weir Farm National Historic Site	143
Scotts Bluff National Monument	142
Cape Cod National Seashore - Salt Pond V.C.	141
Aztec Ruins National Monument	140
Bandalier National Monument	138
William Howard Taft National Historical Site	135
Fort Smith National Historic Site	132
Whiskeytown National Recreation Area	131
Timpanogos Cave National Monument	129
Antietam National Battlefield	127
Jewel Cave National Monument	120
Brown v Board of Education National Historic Site	119
Prince William Forest Park	107
Mount Rushmore National Memorial	105
Alcatraz Island (see Golden Gate NRA)	103
Greenbelt Park	98
Saint Gaudens National Historic Site	97
Coronado National Monument	93
Canaveral National Seashore	93
Little Bighorn Battlefield National Monument	93
Virgin Islands National Park	90
Denali National Park & Preserve	86
Steamtown National Historic Site	70

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Pipestone National Monument	66
Rainbow Bridge National Monument (see Glen Canyon, UT)	61
Lewis & Clark NHT/NPS Midwest Regional Office	53
Point Reyes National Seashore	50
Chickasaw National Recreation Area	48
Black Canyon of the Gunnison	47
Great Basin National Park	46
Wilson's Creek National Battlefield	45
Fort Moultrie National Monument	42
Fort Davis National Historic Site	42
Wind Cave National Park	40
Lincoln Boyhood National Memorial	38
Fort Union National Monument	35
Harry S Truman National Historic Site	34
Wupatki National Monument	34
Tuzigoot National Monument	34
Great Smoky Mountain NP - Cades Cove Campground	31
Gateway National Recreation Area - Sandy Hook	28
Apostle Islands National Lakeshore	27
Vicksburg National Military Park	27
Redwood National Park	27
Mississippi National River & Recreation Area	24
Natural Bridges National Monument	23
Chickamauga and Chattanooga NMP- Lookout Mountain	22
Saratoga National Historical Park	20
Pipe Spring National Monument	18
Theodore Roosevelt National Park - North Unit	12
Great Smoky Mountains NP - Sugarland VC	12
Great Smoky Mountains NP - Oconaluftee Visitor's Center	10
Biscayne National Park	10
Isle Royale National Park	7
Alaska Public Lands Visitor Center - Anchorage	7
Johnstown Flood National Memorial	6
Herbert Hoover National Historical Site	5
Marsh-Billings-Rockefeller National Historical Park	5
Fort Necessity National Battlefield	4
Great Smoky Mountains NP - Smokemont Campground	3
Tuzigoot National Monument	3
Valles Caldera National Preserve	3
Homestead National Monument of America	2
Kings Mountain National Military Park	2
Glen Canyon NRA (both AZ and UT)	2
San Antonio Missions National Historic Park	2
Allegheny Portage Railroad National Historic Site	1

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USACE	**10,477**
Mississippi River Project	2,283
Philpott Lake	1,349
Allatoona	969
Falls Lake	695
Wappapello Lake	477
Table Rock Lake	416
Proctor lake	396
Lake Shelbyville	365
Gull Lake Recreation Area	360
Englebright Lake	318
Raystown Lake Project	245
Willamette Valley Project (Cottage Grove/Dorena)	240
Sam Rayburn Lake	235
Crosslake Recreation Area	215
Jordan Lake	195
Sandy Lake Recreation Area	191
Carters	176
Cochiti Lake	159
Greers Ferry Lake	153
Woodruff-Seminole	150
W. Kerr Scott Dam and Reservoir	144
Success Lake	124
Bonneville Lock and Dam- Bradford Island Visitor Center	115
John H. Kerr Dam and Reservoir	112
Cordell Hull Lake	75
Thurmond Project	50
Eastman Lake	50
Black Butte Lake	49
Cottage Grove Lake - Pine Meadows Campground	38
Leech Lake Recreation Area	27
Lanier	26
Gillham Lake	23
Mark Twain Lake	14
Taylorsville Lake	6
West Hill Dam	6
Buffumville Lake	3
Coralville Lake	3
The Dalles Lock and Dam- Visitor Center	3
J. Percy Priest Lake	2
North Hartland Lake	2
Clinton Lake Project	2
Smithville Lake Project	2
Eau Galle Recreation Area	2
Tioga-Hammond Lakes Project	1

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5.8%

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Barren River Lake	1
Pine Creek	1
Cowanesque Lake Project	1
Abiquiu Lake	1
Hensley Lake	1
Keystone Lake	1
Georgetown Lake	1
Canton Lake	1
Hop Brook Lake	1
Shenango River Lake	1
Bay Model Visitor Center	1

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17-01174_013605;17-01174_013605;17-01174_013606;17-01174_013607

To: Nichols, Ryan[ryan_nichols@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-08-30T13:21:12-04:00
Importance: Normal
Subject: Fwd: Climate discussion
Received: 2017-08-30T13:23:10-04:00
Uncertainty discussion for Summary.docx
KRBS_Full_Report_Final.ig.docx

Here are the two documents.
---------- Forwarded message ----------
From: **Goklany, Indur** <indur_goklany@ios.doi.gov>
Date: Thu, Jun 22, 2017 at 4:32 PM
Subject: Fwd: Climate discussion
To: "Nichols, Ryan" <ryan_nichols@ios.doi.gov>

Attached is the material I sent to Amanda last month. Also, the uncertainty language as originally drafted by Amanda is in the following thread in **bold**.
---------- Forwarded message ----------
From: **Goklany, Indur** <indur_goklany@ios.doi.gov>
Date: Thu, May 25, 2017 at 11:20 AM
Subject: Re: Climate discussion
To: "Erath, Amanda" <aerath@usbr.gov>
Cc: David Raff <draff@usbr.gov>, Marketa Elsner <mmcguire@usbr.gov>, Avra Morgan <aomorgan@usbr.gov>, "Dahm, Katharine" <kdahm@usbr.gov>, Arlan Nickel <anickel@usbr.gov>

Amanda,
Attached are my comments/edits to Chapter 3.9 of the main report and suggestions for the uncertainty discussion in the Summary Report.

I also received a copy of the Niobrara Report (only the Summary and appendices). But my suggestion is let's do one at a time. Once we have wrestled with the Klamath report, it should be easier to address that.

Thanks, and best regards.

Goks

On Thu, May 18, 2017 at 5:05 PM, Erath, Amanda <aerath@usbr.gov> wrote:

> Hello Goks,
> Below is the uncertainty language that we have drafted to be added to the Klamath River Basin Study Summary Report. I have also attached the Klamath River Basin Study Full Report. Sorry for the oversight in not sending the Full Report to you. The Full Report includes uncertainty discussions near the end of chapters 3, 4, 5, and 6 (identified in the table

of contents for each chapter). We have made some additions to the uncertainty discussion in section 3.9.1 to specifically address bias correction. Please let me know if you have any questions.

[redacted]

Amanda Erath
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P.O. Box 25007
Denver, CO 80225-0007

Office: (303) 445-2766
Email: aerath@usbr.gov

On Fri, May 12, 2017 at 8:55 AM, David Raff <draff@usbr.gov> wrote:

Thanks. We'll read as well and incorporate into our uncertainty language as appropriate.

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:

[redacted]

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted]

17-01174_013605;17-01174_013605;17-01174_013606;17-01174_013607

[redacted]

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

The information presented in this report was developed in conjunction with basin stakeholders and is intended to inform and assist stakeholders by identifying potential future scenarios for long term planning. The analyses provided in this report reflect the use of best available datasets and data development methodologies at the time of the study. In accordance with common practice, the impacts assessment methodology employed here is based on using a series of models with the outputs of one model serving as the input to the next model. Since there are uncertainties associated with each model step, and the inputs driving each model step are themselves uncertain, this can lead to a "cascade of uncertainty" (IPCC 2007, here), although there may be situations where one model's tendency to over- or under-estimate may be countered at least to some extent by another's tendency to err in the other direction. While this study has not developed an estimate of the cumulative uncertainties in the results based on this methodology, it is important to acknowledge the uncertainties inherent within projecting future planning conditions for water supply and demand. For example, projections of future climate, population, water demand, and land use contain uncertainties that vary geographically and temporally depending on the model and methodology used. Trying to identify an exact impact at a particular place and time remains difficult, despite advances in modeling efforts over the past half-century. Accounting for these uncertainties, Reclamation and its stakeholders used a scenario planning approach that encompasses the estimated range of future planning conditions.

Significant potential sources of uncertainties include:

- [I would include a brief list based on the Uncertainty discussions in the various chapters (as modified).
- As the first bullet, I would nominate the following: "GCMs perform better at the global rather than regional or basin levels. Moreover, based on preliminary information (~15 years' worth of data), GCM estimates of the rate of global warming may be running too high. However, the use of bias corrected models may reduce, if not eliminate, some of the systematic biases."]
- Another bullet: "The modeling effort did not account for changes in the composition of vegetation or the direct effects of CO_2. The latter includes potential increases in photosynthetic rates and water use efficiency in vegetation. An increase in water use efficiency might help reduce agricultural water demand, and, unless overwhelmed by an increase in production, it might increase runoff, soil moisture and groundwater recharge."

More detailed information about uncertainties related to each part of the study is available in the Klamath River Basin Study Full Report.

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RECLAMATION
Managing Water in the West

Final Report

Klamath River Basin Study

Technical Memorandum 86-68210-2016-06

Prepared by:
Klamath River Basin Study Technical Working Group

U.S. Department of the Interior
Bureau of Reclamation

State of California
Department of Water Resources

State of Oregon
Water Resources Department

March 2016

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Abbreviations and Acronyms

AF	acre-feet
AFY	acre-feet per year
BA	Biological Assessment
Basin Study	Klamath River Basin Study
BCSD	bias corrected and statistically downscaled
BiOp	Biological Opinion
BLM	Bureau of Land Management
CDFG	California Department of Fish and Game (became CDFW in 2013)
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
CEQA	California Environmental Quality Act
cfs	cubic feet per second
CMIP3	Coupled Model Intercomparison Project, Phase 3
CMIP5	Coupled Model Intercomparison Project, Phase 5
COPCO	California Oregon Power Company
CRLE	complementary relationship lake evaporation
CRS	Congressional Research Service
CT	central tendency
CVP	Central Valley Project
degrees C	degrees Celsius
degrees F	degrees Fahrenheit
DPS	distinct population segment
DRI	Desert Research Institute
EIS/EIR	environmental impact statement/environmental impact report
ENSO	El Niño/southern oscillation
EOM	end of month
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ET	evapotranspiration
ET_c	crop evapotranspiration
ET_o	reference evapotranspiration
FAO	Food and Agriculture Organization of the United Nations

FERC	Federal Energy Regulatory Commission
GCM	general circulation model
GDD	growing degree days
gpcd	gallons per capita per day
HD	hot-dry
HDe	ensemble hybrid delta method
HUC	hydrologic unit code
HW	hot-wet
Interior	U.S. Department of the Interior
IPCC	Intergovernmental Panel on Climate Change
KAF	thousands of acre-feet
KBPM	Klamath Basin Planning Model
KBRA	Klamath Basin Restoration Agreement
KHSA	Klamath Hydropower Settlement Agreement
LKNWR	Lower Klamath National Wildlife Refuge
M&I	municipal and industrial
MODFLOW	modular finite-difference flow (model)
MWAT	maximum weekly average temperature
NEPA	National Environmental Policy Act
NIWR	net irrigation water requirement
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWR	National Wildlife Refuge
OWRD	Oregon Water Resources Department
PDO	Pacific decadal oscillation
PDSI	Palmer drought severity index
P_e	effective precipitation
PET	potential evapotranspiration
P.L.	Public Law
PM	Penman Monteith dual crop coefficient method
Prcp	mean annual precipitation
Project	Reclamation's Klamath Project
PRMS	precipitation runoff modeling system
Reclamation	Bureau of Reclamation
RBM10	River Basin model-10
RO	runoff

SECURE	Science and Engineering to Comprehensively Understand and Responsibly Enhance
SONCC ESU	Southern Oregon/Northern California Coast Ecologically Significant Unit
SWE	snow water equivalent
Tavg	mean daily average temperature
T_{max}	maximum daily air temperature
T_{min}	minimum daily air temperature
TMDL	total maximum daily load
TWG	technical working group
UKL	Upper Klamath Lake
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIC	variable infiltration capacity (model)
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WD	warm-dry
WW	warm-wet
WWCRA	West-Wide Climate Risk Assessments

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Chapter 1
Klamath River Basin Study Introduction

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Contents

Figures

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Chapter 1 Introduction

1.1 Background

The Klamath River Basin is the second largest watershed in the State of California (approximately 15,700 square miles), after the Sacramento River Basin (approximately 27,900 square miles; see Figure 1-1). Approximately 60 percent of the watershed is public land (U.S. Geological Survey [USGS], 2007). It supports habitats and numerous fish and wildlife species in addition to supplying water for agriculture, hydropower, recreation, the environment, and tribal, municipal, industrial, and domestic uses. The watershed is divided by the Cascade and Siskiyou Mountains, which create two distinct climates: an arid climate in the upper basin, generally east of the mountains, and a maritime climate in the lower basin. The upper portion of the basin covers approximately 38 percent of the watershed but contributes only 12 percent of the entire watershed's annual flow (Congressional Research Service [CRS], 2005). The lower portion of the basin covers approximately 62 percent of the watershed, yet contributes 88 percent of the watershed's annual flow. The primary tributary inflows are located in the Lower Klamath Basin and include the Shasta, Scott, Salmon, and Trinity Rivers.

The Klamath River Basin has a history of complex water management challenges, dating back more than a century. In large part, these challenges relate to the competing needs of the various mainstem users, irrigation diversions on the Scott, Shasta, and Trinity Rivers (tributaries to the Klamath), and the construction of six mainstem dams (see Figure 1-1), which have altered the natural flow and nutrient and sediment regimes in the river and have inhibited upstream passage of migratory fish above Iron Gate Dam (river mile 190).

Managers of natural resources in the Klamath River Basin have long called for a comprehensive and integrated approach to water management. In 2008, the National Research Council reported that "the most important characteristics of research for complex river-basin management were missing for the Klamath River: the need for a 'big picture' perspective based on a conceptual model encompassing the entire basin and its many components" (Thorsteinson et al., 2011).

[1] Figure 1-1 produced by Michael Neuman, Klamath Basin Area Office of the Bureau of Reclamation

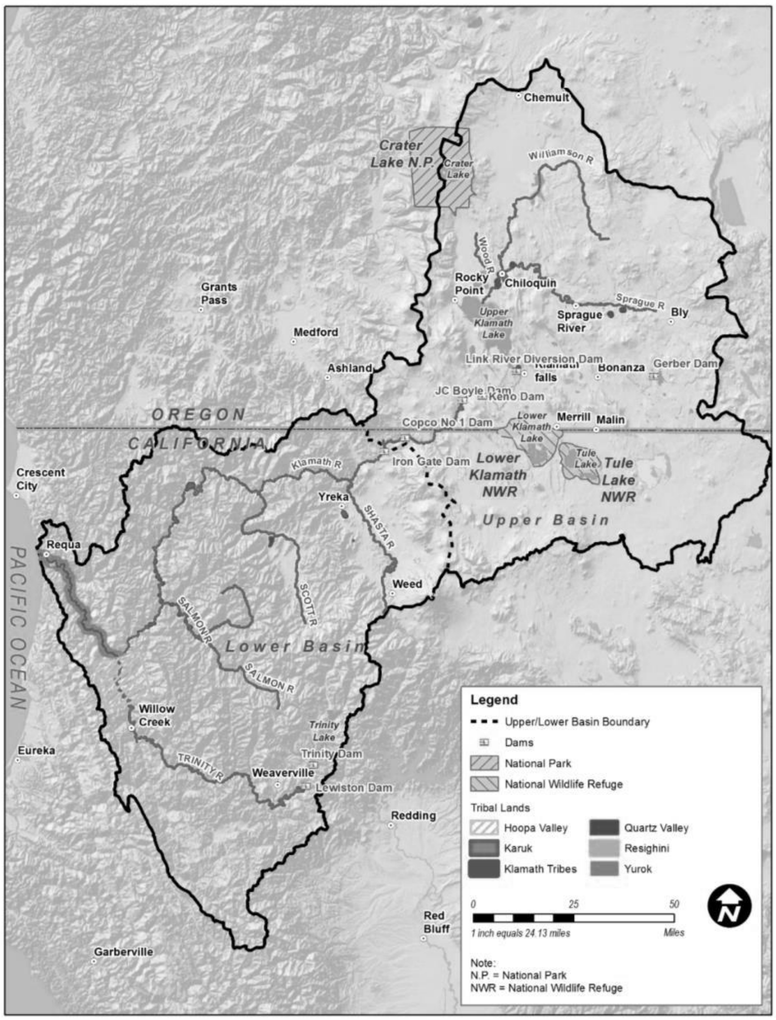

Figure 1-1. Klamath River Basin overview map

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to achieve future water security. The Bureau of Reclamation (Reclamation) serves as the U.S. Department of the Interior's (Interior) primary water management agency. It developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (Public Law

[P.L.] 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program, which was developed as a result. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management.

The Klamath River Basin Study commenced in September 2012. Non-federal cost share partners for the study include the California Department of Water Resources (CDWR) and the Oregon Water Resources Department (OWRD). It should be noted that the Klamath River Basin Study:

- Does not require federal or state environmental review
- Does not contain recommendations for action
- Is not a decisional document

This first chapter of the Klamath River Basin Study provides an overview of the basin, identifies the study purpose, scope, and objectives, and discusses the overall process of the basin study. This chapter also outlines the collaboration and outreach process, which is a significant component of the Klamath River Basin Study.

1.2 Purpose, Scope, and Objectives of the Study

The purpose of the Klamath River Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances. Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessment (WWCRA) but contain additional information, if available (refer to Reclamation [2011d] for water supply assessment; demand assessment is currently under development). The WWCRA is an ongoing complementary activity in the Basin Studies Program in which Reclamation is developing a comprehensive and consistent set of hydro-climate data resources west-wide by incorporating the best available science. These data resources provide a baseline for climate change adaptation planning.

More specifically, basin studies seek to build on existing knowledge through studies, reports, and stakeholder collaboration. The following objectives are key components of each basin study:

- Assess current and projected future water supply
- Assess current and projected future water demand
- Evaluate current and projected future system reliability with respect to chosen performance measures

- Identify and evaluate potential adaptation strategies that may reduce any imbalances

The Klamath River Basin has a long history of water management challenges. Numerous studies have been conducted that evaluate the projected impacts of climate change in the region (e.g., Reclamation, 2011; Risley et al., 2012; Oregon Climate Change Research Institute, 2010; National Center for Conservation Science and Policy, 2010) and explore potential adaptation strategies (e.g., increase offstream storage) that may mitigate the impact. The Klamath River Basin Study seeks to add value to previous and ongoing work in the watershed by evaluating water supply and demand together in a modeling and decision support framework that allows for exploration of a range of management strategies.

1.3 Location and Description of the Study Area

1.3.1 Geographic and Geologic Setting

The Klamath River flows over 253 miles from its headwaters north of (and including part of) Crater Lake National Park in Oregon to its outflow at the Pacific Ocean in Requa, California (Figure 1-1). The Klamath River Basin includes all or parts of Klamath, Lake, Modoc, Siskiyou, Del Norte, Trinity, and Humboldt Counties. Five national forests intersect the Klamath River Basin: Six Rivers, Klamath, Shasta-Trinity, Modoc, and Winema. The Klamath River Basin also contains a substantial amount of land managed by the Bureau of Land Management. From a water management perspective, the basin is divided into two regions, the dividing line being approximately at the location of Iron Gate Dam: the upper portion (hereafter referred to as "Upper Klamath Basin"), and the lower portion (hereafter referred to as "Lower Klamath Basin"). The Upper Klamath and Lower Klamath Basins generally have differing climates and management challenges.

The Klamath River begins in Lake Ewauna, south of Upper Klamath Lake and the city of Klamath Falls, Oregon. The river reach between Upper Klamath Lake and Lake Ewauna is called the Link River. Contributing flows to Upper Klamath Lake originate from the slopes of the Cascade Range and Siskiyou Mountains. The primary tributaries to the Klamath River above Upper Klamath Lake include Wood River to the north, Williamson River to the north, Sprague River to the east, and inflows from the eastern flank of the Cascades. The Klamath River flows southwesterly into California and then west to the Pacific Ocean. The major tributaries entering the mainstem river include the Shasta, Scott, Salmon, and Trinity Rivers. These four rivers all join the Klamath River downstream of Iron Gate Dam and provide 44 percent of the mean annual flow, which heavily influences the hydrology of the Klamath River Basin.[2] The mean annual flow of

[2] Major tributary flow as percentage of Klamath River flow (44%) was reported by BLM (1990) and verified by computing the percentage on a mean annual basis (water years 1951-2012) using the

the Klamath River is about 17,900 cubic feet per second. Eleven miles of the Klamath River between the J.C. Boyle Powerhouse and the California-Oregon border were designated as "scenic" in 1994 under the National Wild and Scenic Rivers System (P. L. 90-452, October 2, 1968). The mainstem lower Klamath River from Iron Gate Dam to the Pacific Ocean, as well as reaches of the Scott River, Salmon River, Wooley Creek (tributary of the Salmon River), and Trinity River, are classified under the National and California Wild and Scenic River Systems (California classifications according to Public Resources Code Section 5093.50 et seq.). These classifications include "wild," "scenic," and "recreational."

The Klamath River contains six mainstem dams (Table 1-1). Link River Dam, at river mile 253 in Oregon, maintains Upper Klamath Lake levels and largely replaced a natural reef that historically formed the lake. Keno Dam, at river mile 232 in Oregon, replaced a natural reef which historically regulated water surface elevations of Lower Klamath Lake (Reclamation, 2005). The remaining mainstem dams were constructed where the Klamath River enters sections of the canyon through the coastal mountain range. These dams were primarily constructed for hydropower production and include: California Oregon Power Company (COPCO) 1 dam at river mile 197 (California); COPCO 2 dam at river mile 198 (California), which was constructed to reregulate flows out of COPCO 1; J.C. Boyle Dam at river mile 227 (Oregon), which was constructed primarily for producing peaking power upstream of the COPCO dams; and, Iron Gate Dam at river mile 190 (California). PacifiCorp (owned by MidAmerican Energy Holdings Company) owns and operates the hydropower producing facilities on the Klamath River under Federal Energy Regulatory Commission license 2082 and provides most of the Klamath River Basin's power (CDWR, 1960).

The Upper Klamath Basin once held pluvial Lake Modoc at an elevation of about 4,200 feet above sea level with an estimated 400 miles of shoreline and 1,000 square miles of surface area. As temperatures warmed during the Late Pleistocene, only Tule Lake, Lower Klamath Lake, and Upper Klamath Lake remained. Parts of the bed of Lake Modoc became Langell Valley and Poe Valley (Beckham, 2006). Lower Klamath and Tule Lakes are discussed further in Section 1.4.2.1. Upper Klamath Basin.

The Klamath River Basin covers three geologic provinces from east to west: the Modoc-Oregon Lava Plateau, the Cascade Range, and the Klamath Mountains. The Modoc-Oregon Lava Plateau includes nearly all of the Klamath River Basin in California east of (and including) Butte Valley. Downstream from Iron Gate Dam and for most of the river's length to the Pacific Ocean, the river maintains a steep, coarse-grained, confined channel. From Iron Gate east to the Oregon-

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following streamflow gages: 1) USGS 11530500 Klamath R. nr Klamath, CA; 2) USGS 11522500 Salmon R. at Somes Bar, CA; 3) USGS 11519500 Scott R. nr Fort Jones, CA; 4) USGS 11517500 Shasta R. nr Yreka, CA; 5) USGS 11530000 Trinity R. at Hoopa, CA. This reported value is based on a simplified water balance which may not be an accurate accounting of the contribution of the four major tributaries to flow in the Klamath River at Klamath, CA.

California state line, the river is predominantly nonalluvial and sediment-supply-limited. The Cascade Range forms a north-south belt through the basin, extending from beyond Crater Lake on the north to Mount Shasta on the south. It is bounded in part on the east by the western edge of Butte Valley and on the west by the western edge of Shasta Valley. The Klamath Mountains province includes the entire remainder of the basin lying west of the Cascade Range (CDWR, 1960).

Table 1-1. Summary of Klamath Basin dams

Dam Name	Location	Klamath River Mile	Year Completed	Reservoir Capacity (acre-feet)	Purpose
Upper Klamath Basin					
Clear Lake[1]	Lost River	NA	1910	527,000	Irrigation
COPCO 1	Klamath River	197	1918	6,235	Hydropower
Link River	Klamath/Link River	253	1921	873,000	Control UKL level
COPCO 2	Klamath River	198	1925	73	Hydropower
Gerber[1]	Miller Creek	NA	1925	94,300	Irrigation
JC Boyle	Klamath River	227	1958	3,377	Peaking power
Iron Gate	Klamath River	190	1962	58,000	Hydropower
Keno	Klamath River	232	1966	18,500	Hydropower, recreation
Lower Klamath Basin					
Dwinnell Dam[2]	Shasta River	NA	1928	50,000	Water supply
Lewiston[2]	Trinity River	NA	1967	14,660	CVP water supply
Trinity	Trinity River	NA	1962	2,400,000	CVP water supply

Notes: CVP = Central Valley Project. UKL = Upper Klamath Lake
[1] Clear Lake and Gerber Reservoirs are briefly discussed in Section 4.2.1, Upper Klamath Basin.
[2] Dwinnell and Lewiston Dams are briefly discussed in Section 4.2.2, Lower Klamath Basin.

1.3.2 Historical Climate and Hydrology

Mean annual precipitation in the basin ranges from as little as 10 inches at lower elevations to more than 70 inches in the mountains to the west (Reclamation, 2011a). About two-thirds of the precipitation falls as snow between October and March. The annual long-term average snowfall in Klamath Falls is about 41 inches per year. Crater Lake (62 miles northwest of Klamath Falls) averages about 521 inches of snow annually.

Historical runoff in the Klamath River Basin is highly variable from year to year. Although precipitation predominantly occurs in the winter months, water percolates and moves through the volcanic soil such that monthly discharge is almost constant in the Upper Basin (CDWR, 1960). Under natural conditions the Upper Klamath Basin area lakes have a significant regulatory effect on the river (CDWR, 1960). A review of historical information in the Klamath River Basin

suggests that, although there may be trends in historical runoff at some sites, they are relatively weak or insignificant (Reclamation, 2011c).

All precipitation and snowmelt in the Shasta River watershed (draining to the Klamath River) percolates into the volcanic soil and appears in springs or discharges directly from the ground water into the Shasta River. The only significant surface runoff from the Cascade Range along the eastern edge of Shasta Valley occurs in the Little Shasta River (CDWR, 1960). In the Scott, Salmon, Trinity, and other tributaries of the lower Klamath River, runoff is a function of precipitation and snow storage (CDWR, 1960).

Since 1900, temperatures in the Pacific Northwest have increased by 1.0 degree Celsius, which is 50 percent greater than the global average, as reported by other studies (Knowles et al., 2007; Regonda et al., 2005; Mote, 2008). Further, the Klamath River Basin, like the western United States overall, has experienced a general decline in spring snowpack, reduction in the amount of precipitation falling as snow in the winter, and earlier snowmelt runoff between the mid- and late-20th century. Although observed trends of temperature, precipitation, snowpack, and streamflow in the western United States might be partially explained by anthropogenic influences on climate (Barnett et al., 2008; Pierce et al., 2008; Bonfils et al., 2008; Hidalgo et al., 2009; and Das et al., 2009), these changes are difficult to distinguish from natural climate variability (Villarini et al., 2009), particularly in the case of precipitation (Hoerling et al., 2010). Similarly, future projections of climate over the next 30 to 50 years indicate that the Klamath River Basin will continue to experience warming, as well as increased winter precipitation and decreased summer precipitation. Natural modes of variability like the El Nino/Southern Oscillation and the Pacific Decadal Oscillation (PDO) will continue to influence these general trends (Thorsteinson et al., 2011).

1.3.3 Vegetation, Wildlife, and Fish

The Klamath Basin is home to a diverse range of plant species. Tree species include willows, pines, ash, oak, cedar, juniper, alder, and birch. Shrubs range from poison oak and sumac to dogwood, manzanita, honeysuckle, currant, mock orange, ninebark, plum, chokecherry, crabapple, snowberry, sagebrush (several varieties), and Oregon grape. Hundreds of indigenous herbaceous plants grow in this region including orchids, lilies, paintbrushes, grasses, ferns, horsetails, and lichens (Beckham 2006).

Wildlife includes numerous mammals, birds, fish, amphibians, and reptiles. Large animals include black bear, black-tailed deer, mule deer, elk, and mountain lion. Smaller mammals range from beaver, ermine, and fisher to bats, river otter, foxes, squirrels, chipmunks, rabbits, shrews, woodrats, and voles. Numerous reptiles live in the area and include the western rattlesnake, garter snake, and pond turtle. Raptors, game birds, woodpeckers, and other water and land birds are at home in this setting. The Upper Klamath Basin is a part of the Pacific Flyway where hundreds of thousands of migrating birds stop to rest. The U.S. Fish and Wildlife

Service (USFWS) listed the northern spotted owl as threatened under the Endangered Species Act (ESA) in 1990, the shortnose and Lost River suckers as endangered in 1988, and the bull trout as threatened in 1999. The National Marine Fisheries Service (NMFS) listed the Southern Oregon/Northern California Coast Ecologically Significant Unit (SONCC ESU) of coho salmon as threatened in 1997 and reconfirmed the listing in 2005, and listed critical habitat for the threatened distinct population segment of the Pacific Eulachon in 2011, which includes the Klamath River estuary. In total three plant, eight fish, seven whale, four turtle, four bird species, and one sea lion in the vicinity of the Klamath River are ESA listed; however, the suckers, coho, and bull trout are most often affected by water management practices.

The Lower Klamath and Tule Lake National Wildlife Refuges (NWR), located in the upper Klamath Basin of Oregon and California, encompass approximately 46,700 and 39,100 acres, respectively (Risley and Gannett, 2006). According to the study by Risley and Gannett (2006), mean annual (2003–2005) water use for the Lower Klamath and Tule Lake NWRs was approximately 124,000 and 95,900 acre-feet, respectively, including precipitation and water deliveries.

The Klamath River is home to numerous resident and migrating fish species. Resident fish resources include redband trout and rainbow trout in the mainstem Klamath River (Beckham, 2006). The shortnose and Lost River sucker reside in the Upper Klamath Basin. Historically, the Klamath River was the third most productive river for salmon in the continental United States. Spring Chinook, fall Chinook, and coho salmon, as well as steelhead, spawn in reaches of the Klamath River and its tributaries.

The six mainstem Klamath River dams were all initially constructed without fish passage; therefore, anadromous fish were cut off from the Upper Klamath River reaches above the COPCO 1 dam site in 1918. They were cut off from an additional 7 miles of river, upstream of Iron Gate Dam (river mile 190) in 1962. Two primary hatcheries were established in the Klamath Basin for raising coho, Chinook, and steelhead: the Trinity River Hatchery, built in 1963, and the Iron Gate Hatchery, built in 1966 (CRS, 2005).

Although the COPCO expressed willingness to construct a single fish ladder at COPCO 1, they and the State of California agreed to close off all runs of anadromous fish and to compensate for the loss of natural runs by stocking the lakes and streams of the Klamath Basin with hatchery-raised fish. Most fishery biologists at the time did not believe fish migration over COPCO 1 via fish ladder was feasible (Beckham, 2006).

Because the SONCC ESU of coho salmon is listed as threatened under the federal ESA, the commercial harvest of these fish has been prohibited. In addition, the Chinook salmon harvest has been restricted in northern California and southern Oregon marine waters for several years to allow the Klamath River to attain the Pacific Fishery Management Council's spawning escapement goals (CRS, 2005).

In 2006 the lack of returning adult salmon to the Klamath River resulted in the closure of several hundred miles of Pacific Coast salmon fisheries (USGS, 2007). Each summer large blooms of the blue-green algae Aphanizomenon flos-aquae in the Upper Klamath Lake lead to low dissolved oxygen and lethal conditions (in part because they produce harmful toxins) for endangered suckers. Major die-offs of suckers occurred in 1986, 1995, 1996, and 1997 (USGS, 2007).

1.4 Present Water and Related Resources Development

1.4.1 History of Settlement

Indigenous people have inhabited the Klamath River Basin since time immemorial (Beckham, 2006). Currently the basin is home to six federally recognized Indian Tribes: the Yurok Tribe; Hoopa Valley Tribe; Karuk Tribe; the Klamath Tribes, comprised of Klamath, Modoc, and Yashookin; Quartz Valley Indian Community; and Resighini Rancheria (77 FR 47868). Numerous additional native groups that are not federally recognized, such as the Shasta people, inhabit parts of Northern California and Southern Oregon. Although they are not federally recognized, some of them have been inducted into the Karuk Tribe (Beckham, 2006).

The Klamath River and canyon are considered sacred by the native tribes (Bureau of Land Management, 1990). The study area includes burial grounds of the Shasta people and their principal ceremonial areas, which are used for spiritual and educational purposes. Native tribes also value the canyon for other important cultural activities. The river area has long been used for fishing, gathering, and hunting; as a meeting place between the area's various tribes and bands; as shared fishing villages; and as a pathway for inter-tribal exchange and communication (Bureau of Land Management, 1990).

Initial Euro-American explorers in the Klamath Basin included fur traders from the Hudson Bay Company as well as surveyors from the United States Navy and Army and emigrant travelers. Settlement began in the mid-1800s, with the discovery of gold in the Lower Klamath Basin, below the Shasta River confluence (Beckham, 2006). Long-term settlement solidified with the passing of the Homestead Act in 1862, which allowed citizens (or those intending to be naturalized) over 21 years old to settle on 160 acres (or less) of land. Railroad development and logging came later due to the rugged terrain in the southern Cascades and Siskiyou Mountains (Beckham, 2006; CDWR, 1960). The Reclamation Act of 1902 initiated a number of federal irrigation projects across the western United States to manage already existing irrigation and to expand settlement in the arid west. Development of Reclamation’s Klamath Project is described in Section 1.4.2. Water Resources Development.

At one time the Klamath watershed was one of the greatest timber-producing regions in the nation (CDWR, 1960). The Klamath River and tributaries were historically used to transport logs to mill sites. For example, in the late 1800s the

Klamath River Improvement Company drove logs from the Spencer Creek area (west of Keno, Oregon) to the California-Oregon state line. Splash dams made of wood and rock were historically used to create surges of water that would facilitate transportation of logs downstream (Beckham, 2006). The timber industry continues to be a significant portion of the regional economy, despite declines since the late 1970s and early 1980s.

Recreational facilities like campgrounds and trails have drawn many tourists annually into the area including Crater Lake, the Modoc Lava Beds, the Trinity Alps, Marble Mountain Primitive Areas, and the coastal redwoods (CDWR, 1960). River reaches between JC Boyle Dam and Iron Gate Dam, as well as below Iron Gate Dam, are major destinations for commercial and private white-water rafting and kayaking (CRS, 2005).

1.4.2 Water Resources Development

1.4.2.1 Upper Klamath Basin

The passing of the Reclamation Act in 1902, in addition to legislation passed by Oregon and California to transfer ownership of land to the federal government, led to the development of the Klamath Irrigation Project (Figure 1-2). The initial project was completed in 1907. By 1924 portions of Lower Klamath and Tule Lakes were drained to uncover additional desirable farmland. In addition, dams were built to facilitate diversions and produce hydropower for the region (Reclamation, 2000).

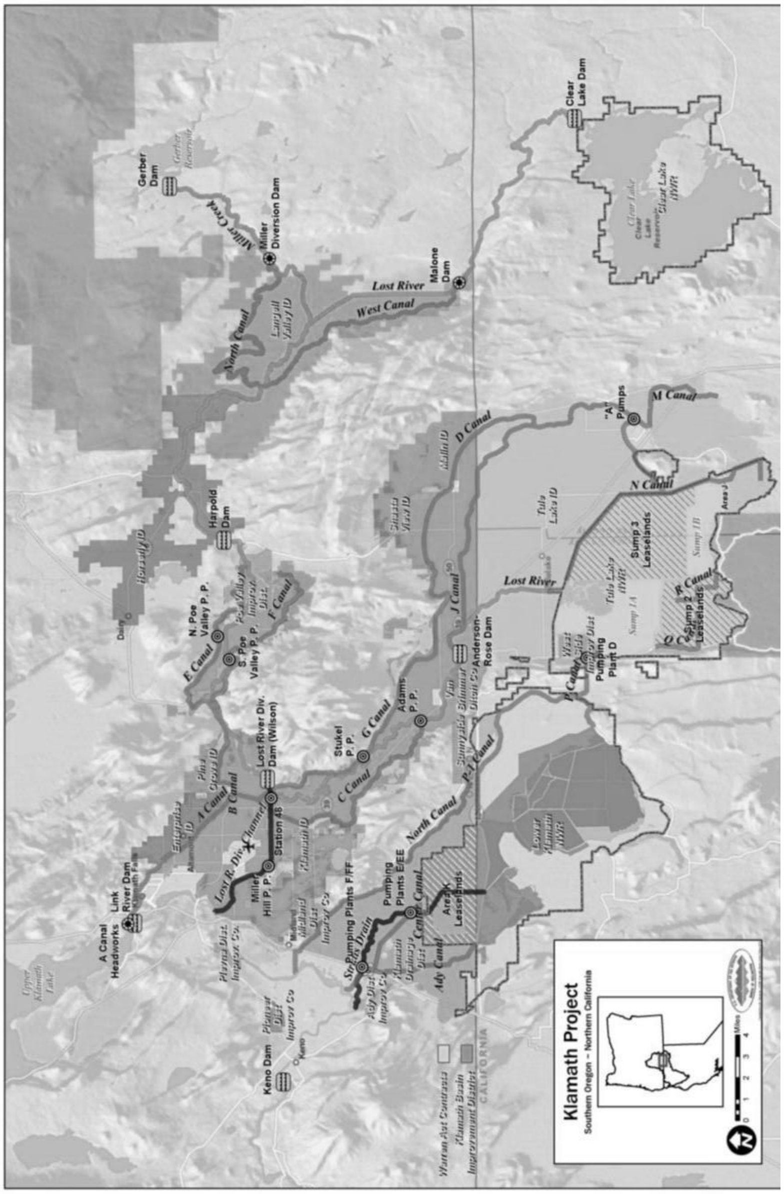

Figure 1-2. Klamath Irrigation Project map

Reclamation's Klamath Project is primarily fed by Upper Klamath Lake and the Lost River system, which includes Clear Lake Reservoir on the Lost River and Gerber Reservoir on tributary Miller Creek (refer to Table 1-1). Releases from Clear Lake and Gerber Reservoirs are delivered to the east side of the Klamath Project to irrigate lands in Langell Valley. The Lost River also receives water from Bonanza Springs located in Bonanza, Oregon. During the irrigation season, flows from the springs in the Lost River may be available for irrigation (Reclamation, 2012).

Prior to development of Reclamation's Klamath Project, the Klamath and Lost River Basins were linked by a flood channel, the Lost River Slough, which allowed water from the Klamath River to enter the Lost River and flow to Tule Lake during high runoff conditions. The two watersheds are now linked by the Lost River Diversion Channel, which facilitates water management and surface delivery of water to the Klamath Project, Tule Lake NWR, and Lower Klamath NWR. During the wet periods of the year water is diverted to the Klamath River; during the drier periods irrigation water is diverted to the Lost River from the Klamath River for irrigation needs (Reclamation, 2011a).

Reclamation's Klamath Project has historically included approximately 254,000 acres of land. It provides water to approximately 1,400 farms covering about 200,000 acres as well as about 27,000 irrigable acres of refuge lands. Principal crops raised on Reclamation's Klamath Project include alfalfa, irrigated pasture, small grains, and potatoes. Onions, horseradish, mint, and strawberry plants are also grown (Reclamation, 2011a; CRS, 2005). In 2011 the Klamath Project's gross crop values were estimated at $204 million (Reclamation, 2012). Water released from one of the project's storage reservoirs may be reused several times before it is returned to the Klamath River. Some of the return flows provide water to the Lower Klamath NWR and the Tule Lake NWR. Excess water and water released from NWR lands is returned to the Klamath River via the Klamath Straits Drain.

Additional irrigation in the Upper Klamath Basin occurs in Butte Valley, California, where the Butte Valley Irrigation District supplies water for approximately 4,000 irrigated acres in the southern end of the valley (CDWR, 1960).

1.4.2.2 Lower Klamath Basin

The Lower Klamath Basin also supports agriculture, but to a lesser extent than the Upper Basin. As of 1997 the number of Lower Basin farms was about 40 percent of those found in the Upper Basin, and agricultural production was estimated to be less than half the value of Upper Basin agriculture ($114 million compared to $283 million) (CRS, 2005).

There are four organized irrigation districts in the Shasta Valley (approximately 10,000 irrigated acres). The Dwinnell Dam, forming Dwinnell Reservoir, or Lake Shastina (Table 1-1), is maintained by the Montague Water Conservation District,

the largest of the Shasta watershed irrigation districts. About 24,000 acres within the Shasta Valley, but lying outside the irrigation districts, are served by individual diversions from various streams (CDWR, 1960). The only known trans-boundary diversion into the Klamath River Basin is from the Sacramento River Basin in California. About 4,000 acre-feet seasonally are diverted into the basin and used for irrigation purposes in the extreme southern end of Shasta Valley.

The Scott River Irrigation District is the single major organized water provider in Scott Valley, California. The district serves approximately 3,500 irrigated acres (CDWR, 1960). Surface water supplies for irrigation are supplemented by pumping of ground water. Most of the irrigated area in Scott Valley, however, lies to the west of the river and is supplied by individual development (CDWR, 1960).

There are additional small cultivated areas in the Lower Klamath Basin, including Hayfork Valley, a portion of the Hoopa Valley Indian Reservation on the Trinity River, and small areas in the vicinity of Lewiston and Seiad Valley (CDWR, 1960).

The Trinity River, the lowermost tributary of the Klamath River, provides water to the California Central Valley Project (CVP), another federal project (CRS, 2005). The Trinity River Division of the CVP was completed in 1964. The Trinity River is the largest tributary of the Klamath River. It enters the Klamath River about 20 miles upstream of its mouth at the Pacific Ocean. The Trinity River Diversion diverts and exports water from the Trinity River system by means of dams, reservoirs, tunnels, and power plants to the Sacramento River (CRS, 2005). At one time, nearly 90 percent of the water in the Trinity River was exported to the Central Valley (CRS, 2005). However, a 2000 Record of Decision reduced that percentage to restore fisheries (CRS, 2005). Lewiston and Trinity Dams (refer to Table 1-1) had cut off 109 miles of anadromous fish habitat on the Trinity River (CRS, 2005).

There are two additional trans-boundary diversions from the Klamath Basin, both in the western portion of the Upper Klamath Basin. One diversion is made from Keene Creek by way of Hyatt Prairie Reservoir, and the other diversion is made from Fourmile Creek by way of the Cascade Canal. This diverted water supplies irrigate lands adjacent to Ashland and Medford in the Rogue River Basin (CDWR, 1960).

1.4.3 History of Water Management Challenges

The Klamath River Basin, like many watersheds in the arid western United States, suffers from use beyond the sustainable capacity of the basin (i.e., over-appropriation). This may be due to a number of factors. First, there are physical constraints in the watershed that are unique to the Klamath Basin. Second, federal and state policies with respect to indigenous people and the environment have not been consistent over time, which has contributed to complex

socioeconomic challenges. Finally, regulatory constraints exist in terms of conflicting state and federal policies. This section will briefly describe these constraints as a way of identifying historical and current water management challenges in the basin and to emphasize the need for a comprehensive Klamath River Basin Study to evaluate any identified current and/or projected future imbalances in water supply and demand.

The Klamath River Basin is unique in that the largest agricultural development in the basin occurs in the Upper Klamath, which receives disproportionately low precipitation compared with the rest of the basin. The Upper Klamath Basin has limited suitable sites for reservoir storage; therefore, water users are subject to the effects of climate variability. For example, Upper Klamath Lake, which is the primary source of water for Reclamation's Klamath Project, is relatively shallow and has little carryover storage from year to year, which makes the project highly dependent on current precipitation and snowmelt for water supply (CRS, 2005).

Implementation and enforcement of state and federal water allocation policies has been a challenge. The Klamath River Compact (ORS 542.620; CA Water Code § 5900 et seq.; P.L. 85-222) between California and Oregon was ratified by the states and consented to by the United States in 1957, giving domestic and irrigation users in the Klamath River Basin preference for applications for higher use of water supplies over applications for lower use supplies, defined as recreation, industrial, hydropower, and other uses. Water rights adjudication in California was completed for the Shasta River Basin in 1932 and for the Scott River Basin in 1980, but the mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court, demarking a significant milestone in determining the water rights of the Upper Klamath Basin.

The United States must provide sufficient water to sustain and protect Indian Trust Assets, which include sufficient water to meet treaty rights such as hunting, gathering, and fishery purposes. The Klamath Tribes were terminated in 1954 (Klamath Termination Act, P. L. 587) and then regained federal recognition in 1986. As a result, the Klamath Tribes lost designated reservation land. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the Klamath Treaty of 1864, which may significantly affect water management in the Upper Klamath Basin. Lower Klamath NWR and Tule Lake NWR rely on water from Reclamation's Klamath Project. These refuges have received lower priority for water than irrigators. However, the Lower Klamath NWR (established in 1908) may have federal reserved rights which would advance their priority (CRS, 2005).

Endangered species issues have been an integral component of operating decisions for Reclamation's Klamath Project since the USFWS listed the shortnose and Lost River suckers as endangered in 1988 and the NMFS listed the SONCC ESU coho salmon as threatened in 1997 (CRS, 2005). Management

challenges associated with opposing water needs and policies are illustrated by the events that took place in the early 2000s (described briefly below), which resulted in the largest fish die-off ever recorded in the Klamath River and severe curtailment of irrigation deliveries to Klamath Project irrigators, resulting in economic hardship.

Reclamation is required to comply with the ESA by consulting on the ongoing operations of the Klamath Project with the USFWS and NMFS (the agencies with delegated authority to implement the ESA) to ensure that its operations do not jeopardize listed species or listed or proposed critical habitat. The USFWS has jurisdiction over inland fish and terrestrial species (shortnose sucker, Lost River sucker, and proposed critical habitat for both sucker species). The NMFS has jurisdiction over marine species and anadromous fish (e.g., SONCC ESU coho salmon). In early 2001 a federal district court faulted Reclamation for failing to formally consult with NMFS on the effects of water storage and diversion on downstream coho salmon under its 2000 operating plan, and prohibited Reclamation from making further diversions until it formally consulted on its next (2001) annual plan. Reclamation prepared an operation plan for 2001 which was forecast to be one of the driest years of record. Reclamation prepared a biological assessment (February 13, 2001) which covered operations until April 1, 2001. In April 2001, the USFWS and NMFS each issued final Biological Opinions concluding that Reclamation's proposed operation of the Klamath Project for 2001 would jeopardize the two species of suckers and the population of coho salmon, and it would harm, but not jeopardize, the continued existence of bald eagles. NMFS recommended release of additional water from Upper Klamath Lake for coho salmon, while USFWS simultaneously recommended maintaining higher lake levels. Because of severe drought conditions, there was not enough water to implement both Biological Opinions simultaneously, even without providing irrigation water for farmers. A judge's order prevented Reclamation from fulfilling water orders under contracts to the irrigators whenever flows dropped below the minimum flows recommended in the 2001 NMFS Biological Opinion (Reclamation, 2011e).

Reclamation announced its response on April 6, 2001, implementing proposed alternatives that severely limited the delivery of irrigation water. For the 2001 water year, Reclamation stated that the normal deliveries would be available for lands receiving water from Clear Lake and Gerber Reservoirs (70,000 to 75,000 acre-feet), but no water would be available from Upper Klamath Lake for deliveries to irrigators or to the Lower Klamath NWR (CRS, 2005). Water conservation measures and higher than expected lake levels later in the summer prompted the Secretary of the Interior to announce that up to 75,000 acre-feet would be released from Upper Klamath Lake to assist farmers. However, this came too late in the season to provide significant assistance.

The National Research Council reviewed the scientific decisions of the controversial 2001 Biological Opinions. The National Research Council Committee concluded that scientific data were insufficient to support the Upper

Klamath Lake level management regimes proposed by the 2001 USFWS Biological Opinion. Although Reclamation's written response to the USFWS 2001 Biological Opinion expressed disagreement with the Biological Opinion's conclusions, Reclamation agreed to not deliver any water from Upper Klamath Lake to Klamath Project water users and NWRs from April through September 2001. Water from Gerber and Clear Lake Reservoirs was used for irrigation on and to meet evaporative losses on the NWR. Releases from Upper Klamath Lake were made to meet minimum stream flows; however, the project was operated to modified minimum elevations for Upper Klamath Lake, which deviated from the minimums prescribed in the USFWS Biological Opinion. An above average number of Chinook salmon entered the Klamath River that August and September, while river flows were unusually low due to drought conditions and unusually warm temperatures. These conditions contributed to the death of more than 33,000 adult salmon (primarily Chinook but also coho, steelhead, and others) due to epizootic disease in the first 40 miles of the river (California Department of Fish and Game, 2004; CRS, 2005).

Several ESA consultations since the early 2000s have affected Klamath Project operations. The most recent to date (and to which current operations adhere) is the 2012 Biological Assessment and 2013 Biological Opinion (BiOp) jointly prepared by the USFWS and NMFS on the Lost River and shortnose sucker, the SONCC coho salmon, the Southern distinct population segment (DPS) green sturgeon, and the Southern DPS eulachon, which directs the operations throughout the Upper Klamath Basin and influences river flows from Link River Dam to the Klamath Estuary. The Biological Assessment and Joint BiOp were completed following a multi-year consultation effort between Reclamation, the USFWS, and NMFS to develop a new long-term operations plan that would "allow Reclamation to continue to operate the Klamath Project to store, divert, and convey water to meet authorized Klamath Project purposes and contractual obligations in compliance with applicable state and federal law while meeting the conservation needs of affected listed species in a coordinated manner" (NMFS and USFWS, 2013).

1.5 Future Challenges and Considerations

The Klamath River Basin Study identifies and evaluates potential adaptation strategies to reduce any identified water supply/demand imbalances. Numerous studies have already identified and investigated potential adaptation strategies. To the extent possible, this study builds upon past or existing efforts and encompasses a wide range of options, perhaps even previously rejected strategies that may perform differently under a wider range of evaluation measures.

This study must also consider the regulations that are in place or in progress in the basin, including among other things total maximum daily load (TMDL) water quality criteria established in parts of the watershed, as well as past and existing restoration efforts. For example, this study considers, in a scenario context, the

ongoing negotiations of the Klamath Basin Restoration Agreement (KBRA) and Klamath Hydropower Settlement Agreement and the related Secretarial Determination Process. The following section of this report touches on these considerations in more detail and concludes with recognition of future challenges.

1.5.1 Previously Identified Management Alternatives

Numerous studies have been initiated to investigate options for increased or new storage (including groundwater), demand reduction, and habitat restoration, even before the events of 2001 and 2002. The Klamath Basin Water Supply Enhancement Act of 2000 (P.L.106-489) authorized Reclamation to study the feasibility of increasing storage capacity in the Upper Klamath Basin and Reclamation's Klamath Project through surface or groundwater supplies (CRS, 2005). Potential options were identified and developed in the 1990s through the Klamath Basin Water Supply Initiative, a public input process involving potentially affected state, local, and tribal interests as well as concerned stakeholders (for example, potential new storage in the Long Lake Valley [Reclamation, 2010]). The Initial Alternatives Information Report, Upper Klamath Basin Offstream Storage Study (Reclamation, 2011a) further investigated options including an aquifer storage and recovery groundwater option at Gerber Reservoir and a hybrid option involving aquifer storage and recovery at Clear Lake and surface storage at a new dam (to be named Boundary Dam). However, these investigations have not identified viable options from a cost/benefit perspective.

Water banking has also been proposed as a management strategy. During the water shortage of 2001, Reclamation initiated the Groundwater Purchase Program, a water bank to buy water for fish and wildlife (CRS, 2005). As part of the NMFS 2002 Biological Opinion, Reclamation could avoid jeopardizing ESA threatened coho salmon by creating and implementing a water bank. Eligible farmers could bid to irrigate their lands with groundwater from their own wells in exchange for payment, thereby freeing water from Upper Klamath Lake (CRS, 2005). These pilot water bank programs were successful in meeting NMFS Biological Opinion requirements for the 2003 and 2004 water years. Reclamation employed a combination of land idling and groundwater substitution in an attempt to meet water banking targets for 2005–2011; however, in 2006 the court eliminated the water banking requirement that was part of the NMFS 2002 Biological Opinion (Reclamation, 2011). Groundwater pumping has also been identified as a potential long-term water management strategy. Pumping groundwater provides short-term benefits, but over-drafting of aquifers has long-term consequences that are less clear (CRS, 2005).

A number of entities are undertaking specific projects to improve water quality and restore habitat. For example, the U.S. Department of Agriculture's Natural Resources Conservation Service has a Work Plan for Adaptive Management for the Klamath Basin to mitigate the effects of drought on agriculture. The core objectives of this program are: (1) decreasing water demand, (2) increasing water storage, (3) improving water quality, and (4) developing fish and wildlife habitat.

1.5.2 Development of Water Quality Criteria

Criteria for TMDLs have been established for the Klamath River Basin (including Lost River) through collaboration between the California North Coast Regional Water Quality Control Board, Oregon Department of Environmental Quality, U.S. Environmental Protection Agency (EPA) Regions 9 and 10, and contractors. The TMDLs for the mainstem Klamath River (including an implementation plan for the already approved Lost River TMDL) were approved by the California State Water Resources Control Board and EPA Region 9 in December 2010. NMFS completed its ESA consultation on the Klamath River TMDLs in December 2010 (National Oceanic and Atmospheric Administration [NOAA], 2011). The Oregon Department of Environmental Quality issued a departmental order adopting TMDLs for the listed parameters for the Upper Klamath (Link River Dam to California state line) and the Upper Lost River. The Oregon TMDLs have been submitted to EPA Region 10 for final approval. TMDLs for the Klamath River's major tributaries (Lost, Scott, Shasta, and Trinity Rivers) were previously established. Klamath River Basin TMDLs are summarized in Table 1-2. When TMDLs are developed, water quality criteria are established for sustaining fish and wildlife species, then acceptable waste load allocations are identified. In many cases existing natural conditions exceed established water quality criteria.

Table 1-2. Summary of Klamath Basin TMDLs

Sub-basin or Reach	TMDL
Sprague River, Williamson River, Upper Klamath Lake	Dissolved oxygen, chlorophyll a, pH (2002)
Lower Lost River (Oregon)	Dissolved oxygen, pH, ammonia toxicity, temperature in Lost River tributaries (2010)
Lower Lost River (California)	Nutrients, pH (2008) Temperature (2006)
Klamath River (Oregon)	Dissolved oxygen, pH, ammonia toxicity, temperature, chlorophyll a (2010)
Klamath River (California)	Nutrients, temperature, dissolved oxygen/organic enrichment (2010)
Shasta River	Temperature, dissolved oxygen (2007)
Scott River	Temperature, sediment (2006)
Salmon River	Temperature (2005)
Trinity River	Sediment (2001)

Source: EPA, 2008

1.5.3 Past or Existing Restoration Efforts

Numerous programs have been established in an effort to restore natural function of the Klamath River, to the extent possible, and to encourage recovery of the basin's ESA listed species. This section highlights some of these activities; however, it does not attempt to identify all past and present planning activities.

The Klamath River Basin Fishery Resources Restoration Act of 1986 established the Klamath Fishery Management Council to monitor the fish population and recommend annual fish harvest limits, as well as the Klamath River Basin Fisheries Task Force to advise the Secretary of Interior regarding implementation of the Restoration Program (U.S. Government Accountability Office, 2005). A USFWS office was established in Yreka, CA in 1987 to facilitate implementation and management of the Restoration Program (U.S. Government Accountability Office, 2005). However, due to funding constraints the Restoration Program was left to expire in 2006.

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 required the NMFS to develop a recovery plan for SONCC ESU coho salmon in 2007 (NOAA, 2011). Since the early 1990s, harvesting of the Klamath River fall-run Chinook salmon stock was restricted offshore from California and Oregon due to low returns. However, based on recent increases in naturally spawning adults, the Secretary of the Interior declared Klamath River fall Chinook salmon populations restored in 2011 (NOAA, 2011).

Additional restoration and recovery actions include construction and monitoring of off-channel ponds (initiated in 2010) to address limited winter rearing habitat for ESA-listed coho salmon. Monitoring efforts following construction showed more than 250 juvenile coho salmon moving into the new ponds in Terwer Creek, illustrating the importance of this habitat for overwintering coho salmon. In 2010 NOAA's Open Rivers Initiative provided funding to the Shasta River Fish Passage Project for removal of the Grenada Irrigation District diversion dam. The Nature Conservancy continues to work on the Shasta River Big Springs Creek to restore more than 11 miles of salmon and steelhead spawning and rearing habitat.

The Trinity River Flow Evaluation (USFWS and Hoopa Valley Tribe, 1999) recommended a restoration strategy for the Trinity River that integrates restoration of riverine processes with the instream flow-dependent needs of salmonids. As a result, the Trinity River Restoration Program strives to restore the natural physical processes in the river and create spawning and rearing conditions (including adequate water temperatures) downstream of the dams that best compensate for lost habitat upstream (Trinity River Restoration Program, 2009).

The federal Wetlands Reserve Program is one of several programs implemented by the U.S. Department of Agriculture. Since the program's inception in 1990, it has resulted in the restoration of approximately 30,400 acres of wetlands in Oregon's Upper Klamath River Basin (Duffy et al., 2011).

Some major Reclamation actions to conserve native fish include construction of a fish screen on the A-Canal, completed in 2003; completion of the Link River Dam fish ladder in 2005; numerous monitoring and research studies; and the removal of Chiloquin Dam on the Sprague River to allow suckers access to historic spawning areas in 2008. The USFWS maintains a habitat restoration program and activities on the NWRs, including walking wetlands. The Nature Conservancy restored 7,000 acres of wetlands at the Williams River Delta of Upper Klamath Lake.

1.5.3.1 Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement

A large coordinated Klamath Basin restoration planning effort involving 42 Klamath Basin stakeholders began in 2007 and was completed in 2010. The resulting agreement, the KBRA, takes a multi-dimensional approach that attempts to resolve complex problems by focusing on species recovery while recognizing the interdependence of environmental and economic problems in the Basin's rural communities (Klamath Settlement Group, 2009a). The goals of the KBRA include:

- Restoring and sustaining natural production and providing for full participation in ocean and river harvest opportunities of fish species throughout the Klamath Basin
- Establishing reliable water and power supplies which sustain agricultural uses, communities, and NWRs
- Contributing to the public welfare and the sustainability of all Klamath Basin communities

The KBRA was intended to be implemented alongside the Klamath Hydroelectric Settlement Agreement (KHSA), which lays out the process for conducting necessary additional studies, environmental reviews, and a decision by the Secretary of the Interior (called Secretarial Determination) surrounding the possible removal of the lower four dams on the Klamath River owned by PacifiCorp beginning in 2020. These dams are Iron Gate, COPCO 1, COPCO 2, and J.C. Boyle. The KHSA includes provisions for the interim operation of the dams prior to dam removal, the process to transfer, decommission, and remove the dams, and the transfer of Keno Dam to the Department of the Interior (Klamath Settlement Group, 2009b). On December 31, 2015 the KBRA terminated because federal authorizing legislation was not enacted. The KHSA is still in effect but its interdependent connection to the KBRA requires its amendment to continue. On February 2, 2016 an agreement-in-principle to amend the KHSA was announced between the states of Oregon and California, PacifiCorp, and the US Departments of Interior and Commerce. The ultimate timing of its implementation is not currently known, but the KHSA describes the implementation of the dam removal action in 2020.

A joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) analysis has been performed and a final Environmental Impact Statement/Environmental Impact Report containing 18 alternatives has been completed. Five of the alternatives, including the no project/no action alternative, were carried forward for detailed evaluation. Among the five alternatives carried forward is full implementation of the KHSA and KBRA (Interior and the California Department of Fish and Game, 2011; Thorsteinson et al., 2011).

1.5.4 Future Challenges

The primary challenge of the Klamath River Basin Study is determining how to address the uncertainties related to water management in the basin. For example, the fate of the KBRA and KHSA is unknown at this time. Quantification of potential imbalances in current and projected future supply and demand and subsequent evaluation of identified management strategies would yield vastly different outcomes, depending on whether the four lower Klamath River dams are removed and associated restoration efforts move forward. To address this future challenge, the Klamath River Basin Study takes a scenario approach in order to increase flexibility in evaluating climate change impacts on the baseline system.

1.6 Collaboration and Outreach

The Klamath River Basin Study is a collaborative effort involving Reclamation and two non-federal cost share partners, the CDWR and the OWRD. The study seeks additional tribal and stakeholder involvement through a process described in the Public Participation and Outreach Plan. The Public Participation and Outreach Plan describes the tribal, stakeholder, and public participation process; however, an overview is provided in this chapter. The process of involving tribes and stakeholders is likely to evolve: consequently the plan will be adapted, as needed, as the study gets underway.

The Klamath River Basin Study was guided by a technical working group (TWG), with input from interested organizations and individuals. The non-federal cost share partners (CDWR, OWRD, and Reclamation) comprise the TWG, which was the primary decision making body for the Basin Study and which conducted a peer review of technical deliverables. Interested organizations and individuals were asked to provide input on the study approach and findings throughout the process. These groups or individuals included federal, state, and local governments; tribes; water use organizations; and non-profit groups. The general public was kept apprised of the progress and findings of the Basin Study primarily through existing public meetings that took place across the region. Figure 1-3 illustrates the Basin Study organization.

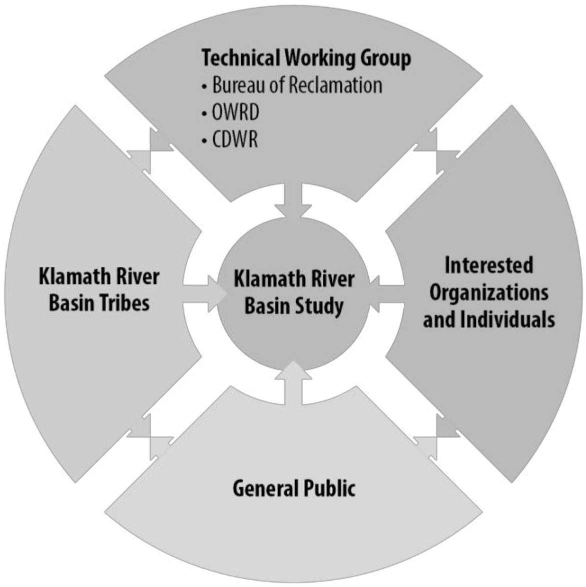

Figure 1-3. Klamath River Basin Study organizational chart

1.7 What to Expect in this Study

The Klamath River Basin Study, consistent with the Basin Study Framework (Reclamation, 2009), contains four primary components. These are listed in Section 1.2, Purpose, Scope, and Objectives of the Study. They are also illustrated in Figure 1-4, which provides an overview of the basin study approach, highlighting Chapter 1. The first component of the Klamath River Basin Study includes an assessment of current and projected future water supplies. Projected scenarios of future water supply are drawn from methods described by WWCRA (Reclamation, 2011d). However, this study also incorporates climate scenarios from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Taylor et al., 2012). The Klamath River Basin Study also utilizes streamflow reconstructions from tree-rings to provide a greater variability context for historical climate and hydrologic conditions. This portion of the study evaluates past and projected future changes in precipitation and temperature, as well as changes in snowpack, evapotranspiration, and groundwater if possible.

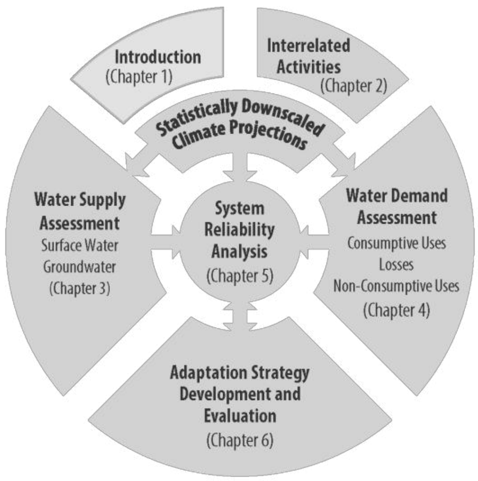

Figure 1-4. Overall approach for Klamath River Basin Study, highlighting Chapter 1

The second component of the Klamath River Basin Study includes an assessment of current and projected future water demands. The assessment includes quantification of historical and projected future agricultural demands and open water evaporation. This study takes advantage of newly available demand information through the WWCRA.

The third component of the Klamath River Basin Study includes evaluating the watershed's ability to meet or withstand any identified future water supply/demand imbalances (these may include infrastructure, fish and wildlife, etc.). System reliability is determined by testing the system against various defined performance measures. These measures were developed with input from the Klamath River Basin Study TWG and interested organizations and individuals. This component relies heavily on projections from the first two components of the study (assessment of current and projected future water supply and demand). The proposed approach includes evaluation of risk and reliability considering multiple scenarios of projected future climate/demand conditions.

The fourth and final component of the Klamath River Basin Study includes identifying and quantifying potential adaptation strategies or opportunities to address potential supply/demand imbalances, considering a range of future scenarios. Adaptation strategies include a range of concepts including operational changes or habitat restoration, among others. In general, the study aimed to identify potential adaptation strategies that that have the potential for reducing water supply/demand imbalances that are likely as a result of climate change.

Adaptation strategies are evaluated using a decision-making framework. Chosen strategies in the Klamath River Basin Study were general in nature in order to evaluate the sensitivity of the basin's water resources to different types of strategies.

The goal for the Klamath River Basin Study is to provide added value to past and ongoing studies to work toward meeting the needs of water users and fish and wildlife in the basin. Further, the Basin Study provides a holistic view of the entire Klamath watershed and does not discount any recommended adaptation strategies. All adaptation strategies identified through the stakeholder and public participation process are included as Appendix E to the Klamath River Basin Study final report.

1.8 Supporting Information

The literature synthesis, along with a list of corresponding references, is provided as Appendix A.

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Chapter 2
Klamath River Basin Study
Identification of Interrelated Activities

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Figures

Chapter 2
Identification of Interrelated Activities

The Klamath River Basin is unique in that its natural setting and inherent challenges require cooperation among all levels of government and organization. The Klamath River Basin is an interstate watershed with six federally recognized tribes. Three ESA listed fish species are directly affected by water use, and these are being managed by a combination of federal, state, and local efforts. The variety of groups with management responsibilities in the basin has resulted in numerous interrelated activities and coordinated efforts. Following is a brief description of interrelated activities in the Klamath River Basin that are relevant to the Klamath River Basin Study. Also, Figure 2-1 illustrates how Chapter 2 fits into the overall basin study approach.

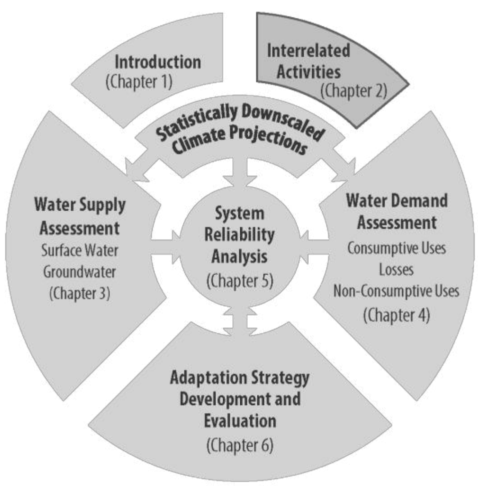

Figure 2-1. Overall approach for Klamath River Basin Study, highlighting Chapter 2

2.1 Federal

Because the Klamath River Basin contains two federal irrigation projects (Reclamation's Klamath Project and a part of the Trinity River Division), provides habitat for species listed as threatened or endangered under ESA, contains one national park (Crater Lake National Park) and thousands of acres of National Forest and Bureau of Land Management Lands, plus is home to six federally recognized native tribes, numerous past and ongoing federal activities overlap and have common goals. The primary common thread that brings various agencies and activities together is the effort to recover three of the basin's seven ESA listed fish species: the SONCC ESU coho salmon (threatened) and Lost River and shortnose suckers (endangered).

Reclamation's Klamath Project first began providing water to irrigators in 1907, and since then the project has grown to about 254,000 acres of land. The Upper Klamath Basin hydrologic system was significantly altered as a result of:

- wetlands drained from Upper and Lower Klamath and Tule Lakes
- construction of dams and conveyance structures by Reclamation
- construction of seven hydroelectric facilities by PacifiCorp
- a Bureau of Indian Affairs dam on the Sprague River, subsequently removed by Reclamation in 2008
- other water diversions and withdrawals above the Klamath Project

Development in the Klamath River Basin over the last century, including construction of dams without fish passage facilities, has caused declines in anadromous and resident fish species. Their decline was recognized in the early 1980s with passage of the Klamath River Basin Fishery Resources Restoration Act (P.L 99-552), which established the Klamath Basin Restoration Fisheries Task Force and charged it with developing a 20-year Klamath River Basin Conservation Area Fishery Restoration Program. This program was allowed to expire in 2006 and no longer operates; however, numerous restoration projects were implemented over the 20-year period.

Since the listing of three Klamath River Basin fish species under ESA, Reclamation has worked with the NMFS (responsible for SONCC ESU coho salmon) and the USFWS (responsible for Lost River and shortnose sucker) on Klamath Project operations plans that reduce regulated flow impacts to these species (Reclamation, 2011f; Reclamation, 2012a). Due to low water availability in 2001, Reclamation was not able to meet irrigation needs or recommended Klamath River flows and Upper Klamath Lake levels for the ESA listed species. As a result, the National Research Council (charged with advising the federal government on science issues) was directed to review the science underlying

recommendations by the NMFS and the USFWS (National Research Council, 2002; National Research Council, 2004; National Research Council, 2008).

In an interim report completed in 2002, the National Research Council concluded that the recommendations had substantial scientific support except for those regarding minimum lake levels of Upper Klamath Lake and increased minimum flows in the mainstem Klamath River. Also, it found Reclamation's Klamath Project operations would not affect tributary conditions, which were deemed the most critical for species survival. At the same time, the National Research Council found Reclamation's proposed minimum Klamath River flows would result in an unknown risk to the population.

In their final report in 2004, the National Research Council corroborated their interim findings and, in addition, provided a broad set of recommendations for the recovery of threatened and endangered species in the entire basin, including expanding the scope of ESA actions by the NMFS and USFWS, planning and organizing research activities and monitoring, identifying specific high priority recovery actions for endangered suckers (e.g., removal of Chiloquin Dam which occurred in 2008), identifying information needs related to SONNC ESU coho salmon, and identifying remediation measures that could be implemented based on current information.

Reclamation has conducted numerous studies with the overarching goal of reducing the Klamath Project impacts on the natural river system. These studies include efforts to evaluate potential new off-stream storage facilities, groundwater pumping and aquifer storage options, and water banking mechanisms. Examples of these studies include the Long Lake Valley appraisal report (Reclamation, 2011a), the Upper Klamath Basin Offstream Storage Investigations, Initial Alternatives Information Report (Reclamation, 2011e), the Klamath Project Yield and Water Quality Improvement Options Appraisal Study (Reclamation, 2012e), and the KBRA On-Project Plan (Klamath Water and Power Agency, 2011).

Other federal agencies have also undertaken numerous activities with the goal of managing natural resources for the livelihoods of Klamath River Basin residents while maintaining, as much as possible, the natural ecosystem critical for ESA listed species and others. The Bureau of Land Management (BLM) has conducted watershed analyses for the mainstem Trinity River (BLM, 1990), for which the goal was to compile existing knowledge about various physical processes important in the basin and work toward more holistic ecosystem management. The BLM was also involved in the process to classify reaches of the Klamath River and its tributaries in the National Wild and Scenic Rivers System (BLM, 1990).

The U.S. Forest Service (USFS) conducted a watershed analysis for the Six Rivers National Forest (Orleans Ranger District) in 2003 to support potential watershed restoration actions related to the recovery of ESA listed anadromous salmonid fish species, and to implement fuels reduction around local

communities, municipal water sources, and private lands as outlined by USFS fire plans (USFS, 2003). The Six Rivers National Forest intersects part of the Lower Klamath Basin. The USFS also completed a land and resource management plan (USFS, 1995) for the Six Rivers National Forest, which takes into account impacts to the ESA listed species.

The USFWS and NMFS work cooperatively with private entities to produce habitat conservation plans for incidental take of fish and wildlife species. The USFWS has also been involved in Trinity River Restoration Program efforts to improve the natural function of the Trinity River below Lewiston Dam. For example, they completed the Environmental Impact Statement/Environmental Impact Report (EIS/EIR) (USFWS et al., 2000) on the Trinity River Flow Evaluation Study, which resulted in the December 19, 2000 Record of Decision to establish the Trinity River Restoration Program (Interior, 2000).

The NMFS has been involved in a wide variety of interagency efforts, including the development of the SONCC ESU coho salmon recovery plan and working with the North Coast Regional Water Quality Control Board to develop TMDLs for the Klamath River in California. The NMFS has also been involved in a number of habitat restoration projects including construction of off-channel ponds by the Mid-Klamath Watershed Council and Karuk Tribe, and installation of a series of boulder step pools to replace gravel push-up dams in a partnership between Scott Valley Resource Conservation District and local landowners (NMFS, 2009; NMFS, 2011).

The KBRA and KHSA are companion agreements between federal agencies, Klamath Basin Tribes, irrigators, fishermen, conservation groups, counties, the states of Oregon and California, and dam owners, which aim to restore Klamath River Basin fisheries and sustain local economies. The agreements include:

- removal of four dams in the upper Klamath River
- increased flows for fish
- greater reliability of irrigation water deliveries
- reintroduction of salmon above the dams and into and above Upper Klamath Lake
- investment in comprehensive and coordinated habitat restoration
- a power program for Klamath River Basin farmers and ranchers
- mitigation to counties for the effects of dam removal
- investment in tribal economic revitalization

Current Federal Energy Regulatory Commission (FERC) licenses for the dams expired in 2006. These facilities are now operated on annual licenses using existing operating plans. FERC continues to participate in the ongoing process to determine the fate of the dams.

2.2 Tribal

Tribal activities in the watershed include the Klamath Basin Tribal Water Quality Work Group, which conducts coordinated surface water sampling activities and participates in the Klamath River Basin monitoring program. The Klamath Basin Monitoring Program is a multi-agency organization aiming to implement, coordinate, and collaborate on water quality monitoring and research throughout the Klamath Basin. As an example, Reclamation and the Klamath Tribes have together been collecting water quality data in Upper Klamath and Agency Lakes since 1988.

The Karuk Tribe and the USFS have coordinated on the land management of the Katimiin Cultural Management Area near Somes Bar, California. Management strategies outlined are consistent with both Karuk cultural environmental management practices and the Klamath National Forest Land and Resource Management Plan. The Katimiin Cultural Management Area is where the Tribe's Pikyawish, or World Renewal, ceremonies are concluded each year (CDWR, 2013).

Three of the six federally recognized tribes in the Klamath River Basin have supported the KBRA and KHSA agreements (Klamath Settlement Group Communications Committee, 2009a, b). Although the others also strive for ESA listed species recovery and return of the Klamath River to a more natural condition, some have expressed the position that dam removal would occur more immediately if left to the FERC relicensing process.

The Hoopa Valley Tribe worked alongside Interior to lead the Trinity River Restoration Agreement, which aims to mitigate the detrimental effects of decades of out of basin diversions of Trinity River water to Reclamation's Central Valley Project (USFWS et al., 2000). The Hoopa Valley Tribe worked with the USFWS to complete the Trinity River Flow Evaluation Study, which became the basis for the Trinity River Restoration Agreement (USFWS and Hoopa Valley Tribe, 1999). The Yurok Tribe is also a member of the council governing the Trinity Restoration Agreement.

The tribes in the Klamath River Basin have also conducted or commissioned their own studies to quantify the needs of environmental resources on which they depend. For example, Trihey and Associates, Inc. (1996) sought to quantify the monthly flow requirements of Tribal Trust fish species in the mainstem Klamath River between Iron Gate Dam and the river mouth.

2.3 Interstate (including regional)

California and Oregon have coordinated on several activities involving the Klamath River, which flows between the states. The Klamath River Basin Compact was ratified by the states of Oregon and California in April 1957. The compact was meant to facilitate and promote the orderly, integrated, and comprehensive development, use, conservation, and control of Klamath River water for various purposes. Uses include domestic, irrigation, protection, and enhancement of fish and wildlife, industrial, hydroelectric power production, navigation, and flood prevention.

In addition to water quantity and timing, California and Oregon have coordinated on water quality issues with respect to the development of TMDLs for the mainstem Klamath River and its tributaries. The California North Coast Water Quality Control Board and the Oregon Department of Environmental Quality coordinated on completion of draft TMDLs for respective parts of the mainstem river by 2010. These are both complete and await approval.

PacifiCorps's hydropower facilities in the Klamath River Basin reside in both California and Oregon. As such, California and Oregon have undertaken studies to evaluate effects of these facilities on the environment, as well as potential effects of removal of the dams. For example, the California Coastal Conservancy (2006) evaluated sediment supplies under potential dam decommissioning scenarios.

2.4 State

The Klamath River Basin spans parts of California and Oregon and both states have been involved in management and planning efforts in the basin. In California, the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) aims to act as a nexus between statewide planning efforts and local planning, helping to synchronize the large, complex planning processes, regulations, and priorities at the state level with the locally specific issues, data, concerns, planning, and implementation needs at the local level.

The OWRD and CDFW (which prior to January 2013 was the California Department of Fish and Game) have collaborated with federal agencies and tribes on a number of studies. For example, the Instream Flow Study Phase II (Hardy et al., 2006) for the Klamath River, which was developed to help determine flow needs of ESA listed fish species, was a collaborative effort involving Utah State University, the USFWS, the NMFS, the USGS, the Bureau of Indian Affairs, Reclamation, CDFG, OWRD, the Karuk Tribe, the Hoopa Tribe, and the Yurok Tribe. In another example, the USGS and OWRD collaborated in a study to characterize regional groundwater in the Upper Klamath Basin and develop a groundwater flow model to test management options (Gannett et al., 2007).

2.4.1 Relationship to State Law including State Water Plan

Water rights adjudications in California and Oregon are in different stages of completion. The Shasta Valley in California was adjudicated in 1932, the Scott Valley in California in 1980. The mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court demarking a significant milestone in determining the water rights of the Upper Klamath Basin. The adjudication covers all claims to the use of surface water that predate Oregon's 1909 Water Code. It also covers those referred to as "federal reserved water right" claims. The Circuit will now handle the remaining administrative process prior to issuance of a Court Decree. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the "time immemorial", which may significantly affect water management in the Upper Klamath Basin. The Klamath Tribes have currently agreed not to exercise their rights prior to August 9, 1908. Another significant finding of the Final Order of Determination granted co-ownership of Klamath Project water rights to both Reclamation and Klamath Project water users.

California's water plan update (CDWR, 2013) includes a discussion of activities through the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) as well as a discussion of overall planning activities in the Klamath River Basin. However, most planning activities are carried out by federal agencies and coordinated groups.

Oregon completed its water resources strategy in 2012 and the state legislature has directed that this plan be updated every 5 years (OWRD, 2012). The plan discusses general recommendations for additional groundwater investigations, improved water monitoring, and continued research on the implications of climate change. Like California, Oregon does not direct planning activities in the Klamath River Basin as these are primarily carried out by interagency consortia.

2.5 Local

There are numerous local landowner and water user groups within the Klamath River Basin and many of these interact with interagency planning efforts. One example is the KBRA/KHSA planning process, which involves 42 stakeholder groups including local water managers and land owners. Also, the Klamath Basin Rangeland Trust, a nonprofit organization with the mission of improving water availability in the Upper Klamath Basin, was formed in 2002. The Trust facilitates partnerships between private landowners and public agencies to conserve water resources and restore habitat and wetlands.

Local groups are also involved in the Trinity River Restoration Planning efforts, as many of the restoration projects take place using local resources and expertise. For example, the Coordinated Resource Management Plan Group for the South

Fork Trinity River is a consortium of local landowners and various agencies who are interested in water conservation, habitat improvement, and educational outreach in the South Fork Trinity River. The group is funded by the Trinity River Restoration Program. Also, in coordination with the NMFS, Scott Valley Resource Conservation District and local landowners installed a series of boulder step pools to replace gravel push-up dams in the basin.

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Chapter 3
Klamath River Basin Study
Assessment of Current and Future Water Supply

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Chapter 3 Assessment of Current and Future Water Supply

3.1 Introduction

The purpose of the Klamath River Basin Study is to identify current and projected imbalances in water supply and demand across the entire Klamath River Basin, and to develop and analyze adaptation strategies to help resolve any identified imbalances. A system diagram illustrating the primary components of the Klamath River Basin Study is provided in Figure 3-1.

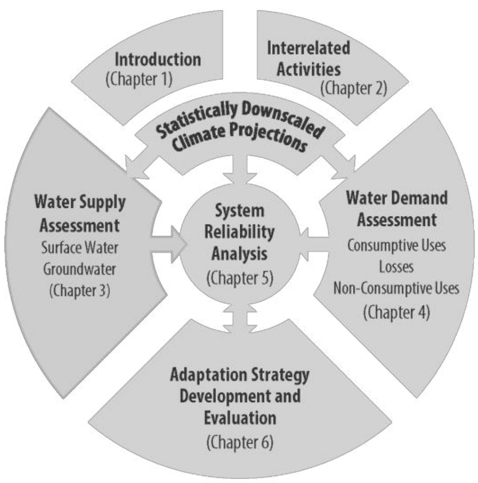


Figure 3-1. Overall approach for Klamath River Basin Study, highlighting Chapter 3

The water supply assessment consists of analyses of both surface and groundwater resources, including quantification of historical trends and projections for two future planning horizons, the 2030s (represented as the mean from 2020–2049) and 2070s (represented as the mean from 2060–2089). The water demand assessment (Chapter 4 of the Klamath River Basin Study) consists of analysis of agricultural, tribal/cultural, environmental, evaporative demands, and domestic, municipal, and industrial demands. Statistically downscaled

climate projections provide the basis for the assessments of projected water supply and demand. They are also used directly, along with supply and demand information, to evaluate the river system with respect to environmental demands such as water quality. Current and projected water supply and demand are brought together to evaluate how the river system has responded historically to changes in supply and demand, and may respond in the future as a result of climate change. Potential water supply/demand gaps are evaluated as part of a system reliability analysis. Performance measures are used to analyze system reliability; these are developed through an input process involving Klamath River Basin Study cost share partners, stakeholders, and tribes. The analysis of system risk and reliability is summarized in Chapter 5.

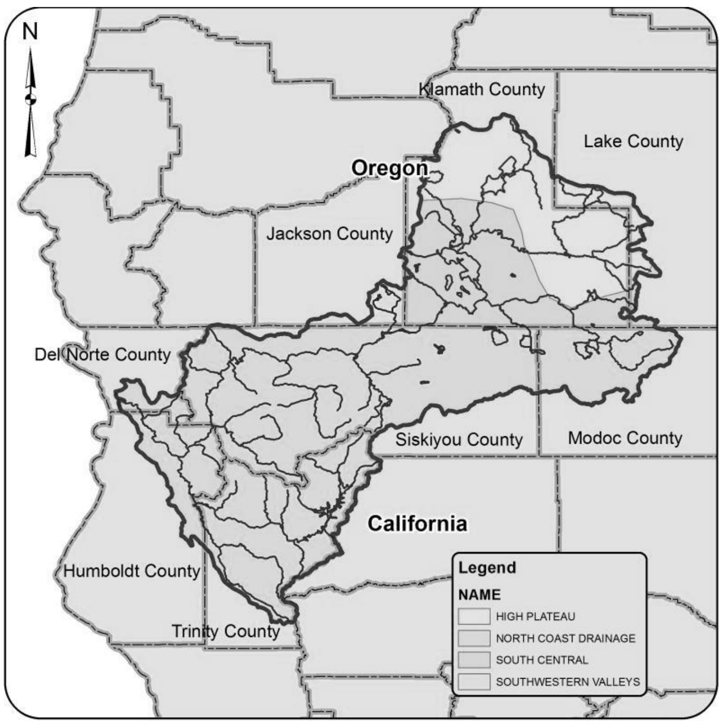
This chapter summarizes the findings of the current and future water supply assessment. The chapter begins with a general discussion of surface and groundwater resources in the watershed, followed by discussions of the technical approach for evaluation of historical water supply (surface and groundwater) and an assessment of historical water supply. The chapter then assesses projected water supply (surface and groundwater), including a detailed discussion of the approach for developing climate scenarios. The assessment of historical and projected surface water supply encompasses the entire Klamath River watershed, while the assessment of historical and projected groundwater supply is focused on three dominant groundwater basins in the watershed: the Upper Klamath Basin, Shasta Valley, and Scott Valley. The difference in approach is due to the extents of existing surface and groundwater modeling tools that may be applied in the study.

3.2 Description of Surface and Groundwater Supplies

This section briefly describes the general characteristics of surface and groundwater in the Klamath River Basin. These characteristics provide context for subsequent analysis of historical and projected water supply throughout the watershed. As previously mentioned, surface water supply is analyzed basin-wide, concentrated on three primary regions for analysis of groundwater supply: the Upper Klamath groundwater basin, the Scott Valley groundwater basin, and the Shasta Valley groundwater basin.

The Klamath River Basin is a complex watershed, due in part to its distinct climatic regions and distinct geologic zones which influence surface and groundwater interactions throughout the watershed. The Klamath River Basin spans four NOAA climate divisions, including High Plateau, North Coast Drainage, South Central, and Southwestern Valleys (Figure 3-2). Climate divisions are generally climatically distinct regions; however, they are also defined by political boundaries, as evidenced on Figure 3-2 where climate divisions are separated by the Oregon-California border and, in one case, by county boundaries (the boundary between Southwestern Valley and South Central).

The elevation ranges of Klamath River Basin climate divisions help to illustrate the complexity of the watershed. Basin-wide elevations range from sea level to about 13,600 feet. These two elevation extremes both fall within the North Coast Drainage climate division. The High Plateau ranges between 4,200 feet and 8,500 feet, while the South Central region ranges between 2,870 feet and 8,000 feet. Even the Southwestern Valley Climate Division, which covers only 15 percent of the watershed, ranges between 3,000 feet and 9,040 feet.



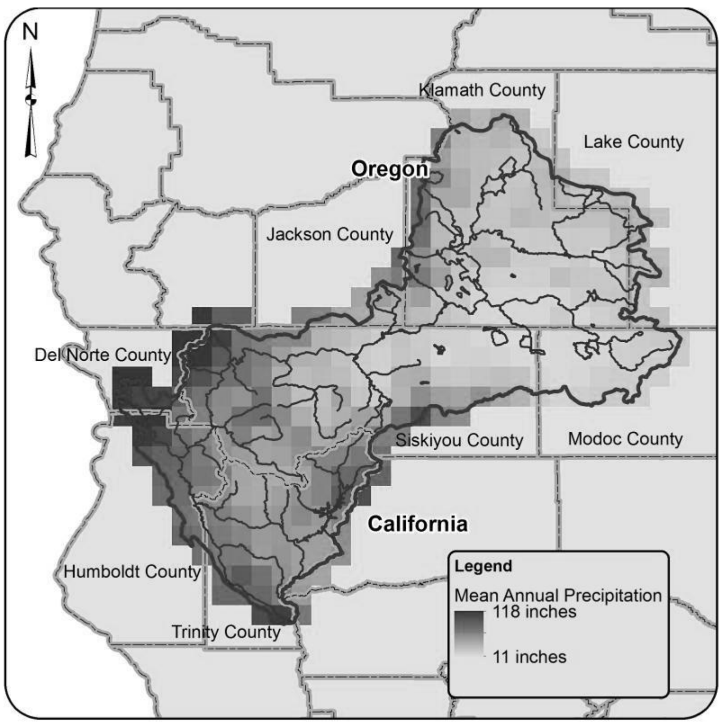
Source: NOAA, http://www.esrl.noaa.gov/psd/data/usclimdivs/boundaries.html.

Figure 3-2. Map of climate divisions within the Klamath River Basin

Mean annual precipitation and temperature were computed for the three dominant climate divisions within the watershed over calendar years 1950–1999, based on a widely used grid-based meteorological dataset developed by Maurer et al. (2002). This historical meteorological dataset is used as the basis for the historical and projected water supply assessments, as discussed later in this chapter.

Mean annual precipitation varies substantially across the three dominant climate divisions within the watershed (Figure 3-3), from about 24 inches per year in the

South Central to about 44 inches per year in the North Coast Drainage and about 26 inches in the High Plateau. The historical basin-wide mean annual precipitation over the same period is approximately 37 inches per year. Mean annual average temperature varies from almost 41 degrees Fahrenheit (F) in the High Plateau to 43 degrees F in the South Central and about 46 degrees F in the North Coast Drainage climate division, with a basin-wide average of 45 degrees F (computed over the same 1950–1999 period as for precipitation).



Source: based on meteorological data from Maurier et al., 2002

Figure 3-3. Mean annual precipitation (inches/year) over the period 1950–1999

The seasonality of precipitation and temperature in the Klamath River Basin is typical of coastal watersheds, where the winter season (defined as December through February) experiences the greatest precipitation, about 18 inches per year for this watershed historically (1950–1999), ranging from about 10 inches per year in the South Central to about 11 inches in the High Plateau and 22 inches in the North Coast Drainage. The summer season (defined as June through August) experiences relatively dry conditions, receiving about 2 inches per year for the same period with less than 12 percent of that experienced in the winter, and

ranging from slightly less precipitation in the North Coast Drainage to slightly more in the High Plateau.

Winter temperatures average about 31 degrees F over the historical period 1950–1999 across the basin and range from about 29 degrees F in the High Plateau and South Central to about 33 degrees F in the North Coast Drainage. Summer temperatures average about 60 degrees F basin-wide and range from about 58 degrees F in the High Plateau to about 60 degrees F in the South Central and about 61 degrees F in the North Coast Drainage. Note that diurnal fluctuations in temperature as well as temperatures at different elevations may vary substantially from these daily averages.

Table 3-1. Summary of Klamath River Basin characteristics

	Basin Wide	North Coast Drainage	South Central	High Plateau
Mean annual precipitation	37 inches	44 inches	24 inches	26 inches
Mean winter precipitation	18 inches	22 inches	10 inches	11 inches
Mean summer precipitation	2.1 inches	1.9 inches	2.1 inches	2.4 inches
Mean annual daily average temperature	45 degrees F	46 degrees F	43 degrees F	41 degrees F
Mean winter daily average temperature	31 degrees F	33 degrees F	29 degrees F	29 degrees F
Mean summer daily average temperature	60 degrees F	61 degrees F	60 degrees F	58 degrees F
Runoff ratio	0.46	0.52	0.27	0.24
Elevation range	0–13,600 feet	0–13,600 feet	2,870–8,000 feet	4,200– 8,500 feet

3.2.1 Surface Water

The Klamath River Basin may be considered a mixed rain and snow influenced watershed. March has historically had the greatest snowpack, averaging about 4.5 inches across the basin (statistics based on historical hydrologic model results are discussed below).

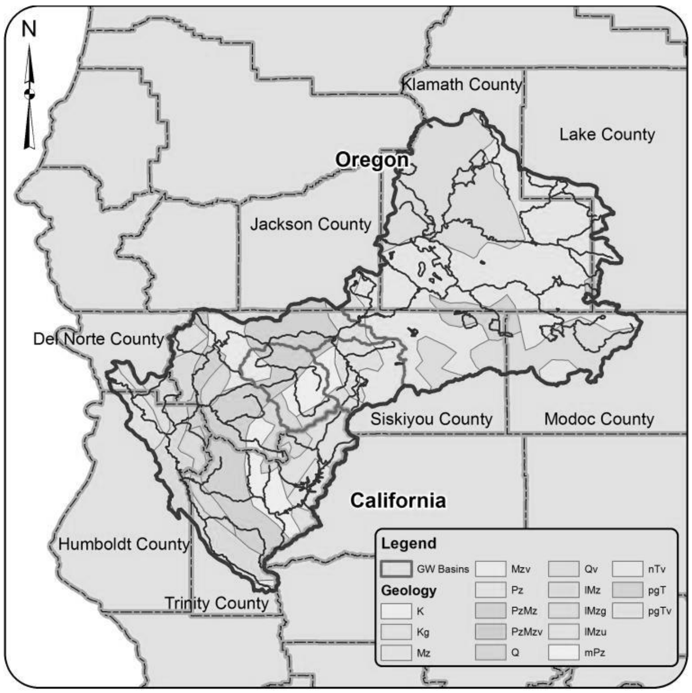
As previously mentioned, the relative magnitudes of key elements of the water balance in the Klamath River Basin vary due to its climatic diversity. Precipitation is one key element of the water balance described above. Other key elements include runoff and evapotranspiration. The ratio of mean annual runoff to mean annual precipitation is an indicator of how much precipitation results in streamflow as opposed to being lost through evapotranspiration or to groundwater recharge. On the whole, the basin has a historical runoff ratio of about 0.46, which translates to 46 percent or almost half of annual precipitation resulting in streamflow. This ratio varies substantially by climate division, from about 0.24 in the High Plateau climate division to about 0.27 in the South Central climate division and 0.52 in the North Coast climate division. In the High Plateau and South Central climate division areas evapotranspiration rates are higher, resulting in lower runoff ratios. In general, over snowmelt-dominated basins of the western

U.S., runoff ratios are typically close to 0.5. Little is known regarding how runoff ratios may change in a changing climate; however, future research may shed light on this question.

3.2.2 Groundwater

Groundwater systems are dynamic, with rates of recharge and discharge and hydraulic head varying in response to external stresses. Climate is one primary external influence on groundwater systems, along with human-caused stresses such as pumping, artificial recharge from canal leakage, and other sources. This section offers an overview of three primary groundwater basins to provide context for analysis of historical and projected future conditions in these areas and to provide greater understanding of how climate and other stressors may influence them.

The Klamath River Basin spans numerous geologic formations including volcanic, sedimentary, and granitic (Figure 3-4 and Table 3-2). Each formation, with its various overlying soil types, causes unique surface and groundwater interactions. Groundwater is an important water source for fish, wildlife, irrigators, and residents throughout the watershed, and in particular the Upper Klamath Basin and Scott and Shasta Valleys. For example, it provides cool, late summer streamflows to sustain fish at a critical time for spawning and rearing. In another example, some irrigators depend on groundwater supply to supplement surface water supplies during low water years where surface water supplies may not fully meet water needs, while many more irrigators depend solely on groundwater supplies. Increasing reliance on groundwater makes this an important component of the water supply assessment.



Source: Generalized Geologic Map of the United States, http://pubs.usgs.gov/atlas/geologic/

Figure 3-4. Map of geologic units within the Klamath River Basin

Table 3-2. Descriptions of Klamath River Basin geologic types by ID as represented in Figure 3-4

ID	Geology	ID	Geology
nTv	Neogene volcanic rocks	IMzu	Lower Mesozoic ultramafic rocks
Qv	Quaternary volcanic rocks	mPz	Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks
Mz	Mesozoic sedimentary rocks	IMzg	Lower Mesozoic granitic rocks
pgTv	Paleogene volcanic rocks	mPz	Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks
pgT	Paleogene sedimentary rocks	Pz	Paleozoic sedimentary rocks
PzMzv	Paleozoic and Mesozoic volcanic rocks	IMzg	Lower Mesozoic granitic rocks
IMz	Lower Mesozoic (Triassic and Jurassic) sedimentary rocks	Kg	Cretaceous granitic rocks
PzMz	Paleozoic and Mesozoc sedimentary rocks	K	Cretaceous sedimentary rocks
Mzv	Mesozoic volcanic rocks	Q	Quaternary deposits

As noted previously, the Klamath River Basin Study water supply assessment focuses on three primary groundwater basins including the Upper Klamath Basin, the Scott River Valley (Scott Valley), and the Shasta River Valley (Shasta Valley). The Upper Klamath Basin includes agricultural areas upstream of Upper Klamath Lake and areas in and surrounding Reclamation's Klamath Project, as well as Butte Valley and the Lost River drainage. Each of the three dominant groundwater basins is described below and highlighted in Figure 3-4.

3.2.2.1 Upper Klamath Groundwater Basin

The Upper Klamath groundwater basin spans about 8,000 square miles upstream of Iron Gate Dam on the Klamath River. Gannett et al. (2012) estimated approximately 500,000 acres of irrigated land for agriculture in 2011. Descriptions of the Upper Klamath groundwater basin primarily come from studies by Gannett et al. (2007) and Gannett et al. (2012).

The Klamath River Basin spans the Cascade Range geologic province (roughly corresponding with the Lower Klamath Basin) and Basin and Range geologic province (roughly corresponding with the Upper Klamath Basin). The Western Cascades sub-province of the Cascade Range constitutes part of the western boundary of the regional groundwater flow system and has very low permeability. The High Cascade sub-province of the Cascade Range consists mostly of volcanic vents and lava flows. There are two main areas in the Upper Klamath Basin with these Quaternary volcanic deposits: near Crater Lake (forming part of the northwest Upper Klamath Basin boundary), and from Mount Shasta east to Medicine Lake Volcano (forming part of the southern Upper Klamath Basin boundary).

Groundwater recharge from precipitation accounts for about 20 percent of the total precipitation in the Upper Klamath Basin. The exact percentage varies spatially and temporally (Gannett et al., 2007). The primary recharge areas in the upper Klamath Basin are the Cascade Range and uplands within and on the eastern margin of the basin. In the northeast part of the Upper Klamath Basin, basalt formations are an important source of recharge due to their high permeability. According to multiple references, at least 60 percent of the inflow into Upper Klamath Lake can be attributed to ground-water discharge in the Wood River sub-basin and springs in the lower Sprague River drainage and the Williamson River drainage below Kirk (Gannett et al., 2007).

Basin and Range Province deposits in the study area include a region from Clear Lake Reservoir eastward to the Upper Klamath Basin boundary. This region generally has low permeability. The region around the Tule Lake sub-basin and to the south consists of major water-bearing volcanic rock from the Late Miocene to Pliocene eras. Rock from these periods consists of volcanic vent deposits and flow rocks. These are generally located throughout the area east of Upper Klamath Lake and Lower Klamath Lake, underlying most of the valley-fill and basin-fill deposits in the study area. The lake deposits near the original lakebeds have much lower groundwater yield due to low permeability and a tendency to

have confining layers. About a mile below J.C. Boyle Dam, a large spring complex contributes significant flow to the Klamath River, on the order of 200 cubic feet per second.

The City of Klamath Falls, which is the primary population center in the Upper Klamath Basin at about 21,000 residents, is entirely supported by groundwater sources. Demand for groundwater has increased in recent decades in the Upper Klamath Basin as a replacement water source for both municipal and agricultural uses.

3.2.2.2 Scott Valley Groundwater Basin

The Scott River is a major tributary of the Klamath River. The Scott Valley sub-basin consists of 813 square miles, approximately 63 percent in private land and 37 percent in federally managed lands (Harter and Hines, 2008). It is fed by a number of tributaries, many of which become dry in the summer months. CDWR Bulletin 118 (2003), which describes California's primary groundwater basins, characterizes the Scott Valley Groundwater Basin as a narrow alluvial floodplain about 28 miles long and ½ mile to 4 miles wide. The basin boundary is generally defined as the contact between the valley alluvium and rocks from the surrounding mountains, dating from Pre-Silurian to Cretaceous. The CDWR Bulletin 118 groundwater basin within the Scott Valley defines the model domain for the assessment of groundwater supply for this region.

The largest water storage in the watershed occurs in the alluvial fill of the Scott Valley groundwater basin, which is recharged annually by the Scott River and tributary streams, and by infiltration of precipitation and snow melt. This flood plain aquifer area was calculated to represent more than half of the total groundwater stored in the Scott Valley (Mack, 1958). The recent alluvium ranges in thickness from less than one foot to greater than 400 feet in the center of the Scott Valley at its widest point. The thickness of the alluvium decreases both to the north and to the south (Harter and Hines, 2008).

The Scott Valley's largest municipalities, Etna and Fort Jones, use a combination of surface and groundwater sources. Most rural residences use wells, but a few are served by springs and surface diversions (Harter and Hines, 2008). Land use is dominated by agriculture and cattle-raising. Almost 90 percent of the agricultural area within Scott Valley is used for alfalfa and pasture (CDWR, 2000). CDWR (2003) estimates that groundwater use for agriculture and municipal/industrial demand is about 1,300 acre-feet (AF), based on the 1991 flow augmentation survey for Scott Valley (CDWR, 1991).

3.2.2.3 Shasta Valley Groundwater Basin

The Shasta River is near the size of the Scott Valley and encompasses almost 800 square miles. The agricultural area within the Shasta Valley is comprised primarily of pasture and alfalfa, which amounts to about 80 percent of the total agricultural area. Many sub-basins of the Shasta Valley have pasture/hay and cultivated crops, which together account for more than 10 percent of the land area.

CDWR Bulletin 118 describes the Shasta Valley as having Quaternary alluvium as the primary formation supporting groundwater. This formation appears continuous throughout the valley region. Mack (1960) also reported volcanic rock formations of the western Cascade Mountains and the ancestral Mount Shasta debris avalanche. The southeastern boundary of the watershed is formed by Mount Shasta, one of the few glacier peaks in California. Glacial melting on Mount Shasta and mountain precipitation are principal sources of groundwater recharge in the Shasta Valley. A portion of this recharge reaches the Shasta River through spring discharge in the vicinity of Big Springs (CDWR, 1991). The CDWR Bulletin 118 groundwater basin within the Shasta Valley defines the model domain for the assessment of groundwater supply for this region.

The hydrology of the Shasta River has been and continues to be affected by Dwinnell Dam (built in 1928 and raised in 1955), surface water diversions, and interconnected alluvial groundwater pumping. Domestic, municipal, and industrial water use information available for the Shasta Valley, which had a population of 18,225 based on the 2000 Census, primarily consists of urban water management plans for the cities of Yreka and Weed, California. Water supply for the City of Yreka, with a population of 7,765 according to the 2010 Census, is completely sourced from surface water. The water supply for Weed, with a 2010 population of 2,967, is comprised of springs and wells.

3.3 Historical Surface Water Availability

This section summarizes historical and current surface water availability in the Klamath River Basin. Specifically, it provides a brief discussion of previous studies, a discussion of data and models used, and an analysis of historical availability and trends. Although the literature synthesis (Appendix A of the Klamath River Basin Study Report) contains a detailed discussion of previous studies, this section touches on those related to historical water supply availability to provide context for the assessment of surface water supplies.

3.3.1 Previous Studies

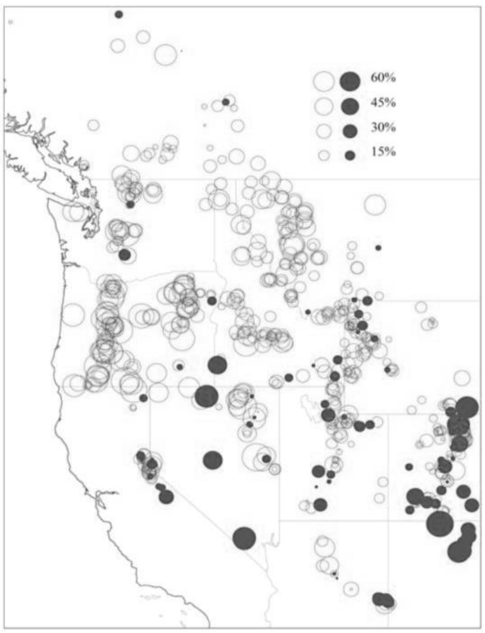
Numerous studies conducted over regions including northern California show increasing trends in historical temperatures, both annually and seasonally (Bonfils et al., 2007; Cayan et al., 2001; Dettinger and Cayan, 1995). Temperature increases over the 20th century have been estimated at 1.7 degrees F (1895–2011 over California by Moser et al., 2012) and 0.2–1.5 degrees F (difference between

1991–2007 and 1961–1990 over Shasta-Trinity National Forest by Furniss et al., 2012). Historical trends in precipitation have been inconsistent. Furniss et al. (2012) found no apparent increase in precipitation variability, but found an increase in winter, defined as January and February (0.1 to 7.9 inches) and growing season precipitation (0.1 to 2.1 inches). Research has shown small increasing trends in the frequency of historical extreme events over the mid-Pacific region (Kunkel, 2003; Madsen and Figdor, 2007; Gutowski et al., 2008).

Historical trends in snowpack and runoff over Northern California include declines in spring snowpack and earlier snowmelt runoff (Knowles et al., 2007; Regonda et al., 2005; Peterson et al., 2008; Stewart, 2009; Furniss et al., 2012; Reclamation, 2011c). However, glaciers on Mount Shasta are among the few in the world that are increasing in size (Furniss et al., 2012). Note that any trends in climate and water balance (i.e., snowpack and runoff) are dependent on the time period of analysis and are a direct result of the combined influences of natural climate variability and climate change (Reclamation, 2011k).

In the Upper Klamath River Basin, dry season (April to September) and summer streamflow (July to September) declined 16 percent and 38 percent, respectively during the period between 1961 and 2009 (Mayer and Naman, 2011). This decline is closely associated with decline in April 1 snowpack, which decreased approximately 40 percent during the same study period for snowcourse sites located below 1820 meters (5,970 feet) in elevation.

In response to temperature increases in the Pacific Northwest (Cayan et al., 2001; Regonda et al., 2005), snowpack in western North America has declined over the past 50 years (Mote et al., 2008). Figure 3-5 illustrates declines in April 1 snow water equivalent (SWE) at 594 locations in the western U.S. and Canada between 1950 and 2000. Mote et al. (2008) noted that the Pacific Northwest (generally including Washington, Oregon, and Idaho) has experienced the largest decline in snowpack in the western U.S. Although many regions have experienced decreasing trends, some regions have experienced increasing trends in April 1 SWE, namely in parts of the southwestern U.S.



Source: Mote et al., 2008

Note: Negative trends are shown by open red circles, positive trends by solid blue circles.

Figure 3-5. Relative trends in April 1 SWE at 594 locations in the western U.S. and Canada, 1950–2000

Attribution studies have aimed to distinguish historical trends due to climate change versus trends due to natural climate variability (Bonfils et al., 2007 and Cayan et al., 2001 for the western United States; Gershunov et al., 2009 for California and Nevada). Bonfils et al. (2008) found that increases in daily minimum and maximum temperatures over 1950–1999 cannot be fully explained by natural climate variability. Pierce et al. (2008) found that climate change may be the cause of about half of reductions in the fraction of annual precipitation falling as snow observed in the western United States from 1950 to 1999. The strongest changes in winter runoff, and in the fraction of precipitation accumulated as snow, have occurred at medium elevations (750–2,500 meters or 2,460–8,200 feet and 500–3,000 meters or 1,640–9,840 feet, respectively) close to freezing level. These are not likely to be associated with natural variability (Hidalgo et al., 2009). Barnett et al. (2008) found that, over the western United States, up to 60 percent of the climate-related trends in streamflow are human induced. These as well as other attribution studies of streamflow timing (Hidalgo et al., 2009 and Das et al., 2009) and snow/rain days (Das et al., 2009) show that statistical significance of the anthropogenic signal is greatest at the scale of the

western U.S. and weak or absent at the watershed scale, except in the Pacific Northwest (Hidalgo et al., 2009). However, attribution of any apparent trends in precipitation to climate change remains difficult (Hoerling et al., 2010).

3.3.2 Approach

The general approach for assessing historical surface water supply in the Klamath River Basin is to evaluate how historical climate has influenced the quantity, timing, and form of precipitation falling on the landscape. Assessment of historical water supply involves (1) evaluating trends in historical climate using a widely used spatially distributed meteorological dataset; (2) utilizing a hydrologic model to simulate the partitioning of precipitation into snow storage, evapotranspiration, runoff, and recharge to groundwater based on meteorological inputs and landscape characteristics; and (3) evaluating trends in historical water balance parameters based on hydrologic model simulations. This overall approach is illustrated by Figure 3-6.

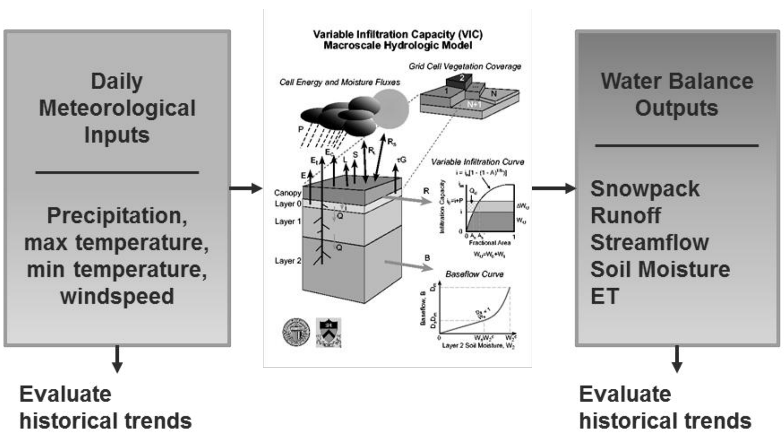


Figure 3-6. Summary of approach for assessment of historical surface water availability

For the Klamath River Basin Study, current and future water supply assessments rely on the variable infiltration capacity (VIC) model for simulation of surface water hydrology. The VIC model (Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) is a grid-based hydrologic model that solves the water balance at a spatial scale of 1/8th degree, or approximately 10 kilometers on a side. Details regarding the VIC model and the configuration used in the Klamath River Basin water supply assessment are provided in Appendix B, Supplemental Information for Assessment of Water Supply; however, details relevant to this study are provided below.

The VIC model requires gridded daily precipitation, maximum and minimum temperatures, and wind speed magnitude (at a minimum) as input to simulate water balance variables. The Klamath River Basin Study utilizes historical gridded observations developed by Maurer et al. (2002) for the period from January 1949 to July 2000. Additional model forcings that drive the water balance, such as solar (short-wave) and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficit, are calculated within the model.

The VIC model outputs may be defined by the user, but typically include grid cell water balance terms such as evapotranspiration, baseflow, or runoff. Gridded surface runoff and baseflow are hydraulically routed to produce streamflow at a select group of locations, using the model presented by Lohmann et al. (1996). Routed streamflow using this approach represents natural streamflow – that is, streamflow that would occur in the absence of water management (i.e., diversions, return flows, and storage). For climate change impact studies, VIC is commonly run in water balance mode due to its higher computational efficiency compared to the alternative energy balance mode, which facilitates numerous projected climate simulations.

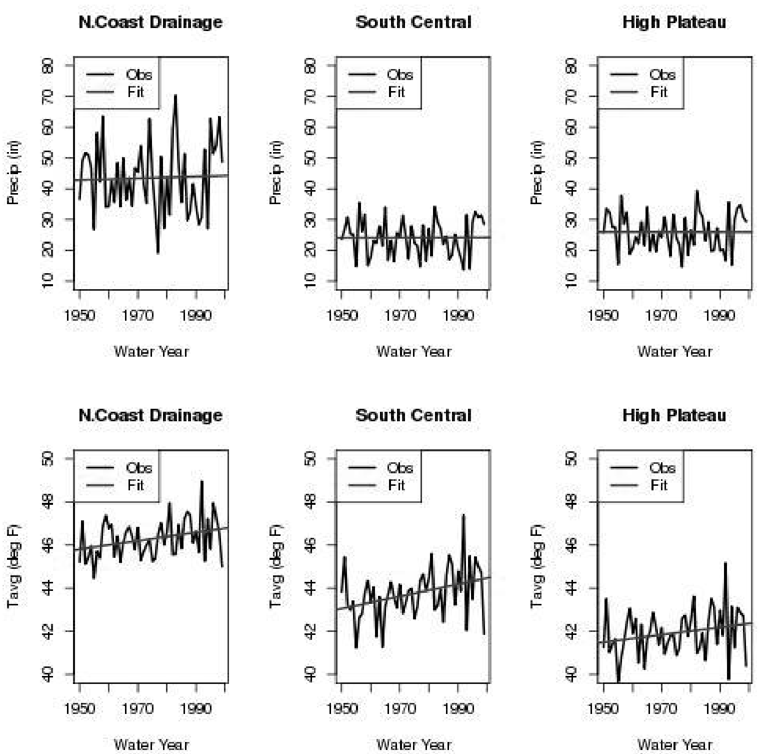
3.3.3 Present Availability and Historical Trends

This section summarizes present climate and surface water availability as well as historical trends. Historical simulated trends in climate and water balance variables are based on data used in the Klamath River Basin water supply assessment. The trends presented for climate (precipitation and temperature) likely have less uncertainty than those based on water balance parameters, primarily because climate trends were computed based on interpolated observations whereas water balance trends were computed based on hydrologic model output. Where appropriate, results are compared with findings from previous studies.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. For example, this dataset was used to develop climate and hydrologic projections developed and supported by Reclamation as part of its West-Wide Climate Risk Assessment (Reclamation, 2011d) and data portal (Archive Collaborators, 2000). The dataset has been extended beyond the original July 2000 date to December 2010 (Maurer et al., 2010). However, we utilized the original dataset as the basis for evaluating historical hydrology in the region to maintain consistency with previous efforts.

Historical trends in April 1 SWE, total annual runoff, total annual evapotranspiration, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model described briefly in the previous section. Because summer months typically receive low precipitation in the Klamath River Basin (see Table 3-1), soil moisture is an important water source

for natural vegetation and perhaps some dryland agriculture. Hence, the Klamath River Basin Study Water Supply Assessment reports trends in June 1 soil moisture, which was found to be the month with maximum soil moisture in the greater watershed. Trends were computed over the entire Klamath River Basin, as well as over the three dominant climate divisions within the basin: North Coast Drainage, South Central, and High Plateau. The fourth climate division within the watershed, Southwestern Valleys, covers only a small portion of the watershed (spanning just five spatially distributed VIC model grid cells). Therefore, data for this region is not summarized.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

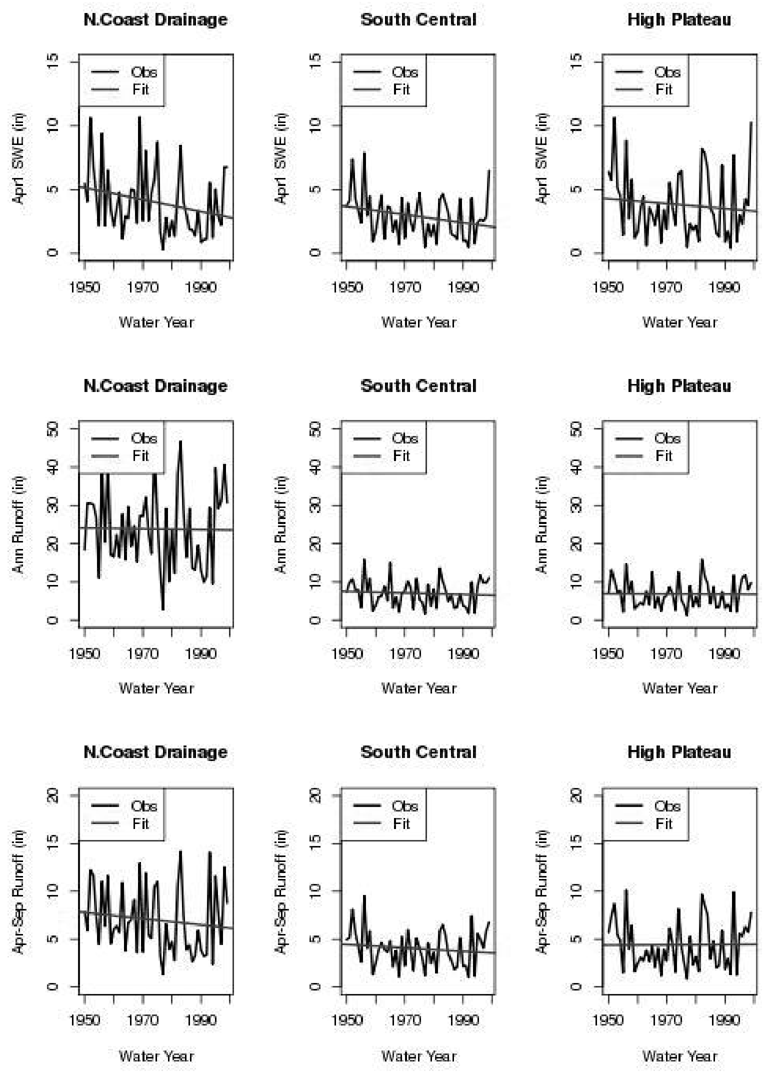
Figure 3-7. Trends in mean annual water balance parameters (precipitation and temperature) over 1950–1999 water years

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50-year period), small but increasing trends over the portions of the basin within the North Coast Drainage and South Central Climate Division (about 1.3 inches [+3 percent] and +0.1 inches [+0.5 percent] over the 50-year period, respectively), and a small decreasing trend over the portion of the basin within the High Plateau Climate Division (-0.03 inches [-0.1 percent]). None of these historical trends is statistically significant at the 95th percentile level (see Figure 3-7 and Table 3-3 for a summary of trends). The combination of both increasing and decreasing historical trends in precipitation over parts of the watershed is consistent with previous findings (Hoerling et al., 2010) showing a lack of clear historical change signal for annual precipitation.

All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999 (Figure 3-7 and Table 3-3). The trends in those portions of the basin within the North Coast and South Central climate divisions, as well as in the basin as a whole, are statistically significant at the 95th percentile level. Historical trends in mean annual temperature (+1 degree F basin-wide and +0.8 to +1.4 degrees F, depending on the climate division) are consistent with previous findings indicating positive change in temperature (Moser et al., 2012; Furniss et al., 2012).

Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide as well as for each of those portions of the basin within the North Coast, South Central, and High Plateau climate divisions (see Figure 3-8 and Table 3-3). Historical trends basin-wide indicate about a 41 percent decrease in April 1 SWE, with a range of about 22 percent to 45 percent over the portions of the basin within the three dominant climate divisions. The range of historical decreases in SWE computed by this study closely corresponds with the reported decrease in Upper Klamath Basin April 1 SWE by Mayer and Naman (2011) of 40 percent over the period 1961–2009, using snow course measurements below about 6,000 feet. Although the computed declines in April 1 SWE may be considered substantial, none are statistically significant at the 95th percentile level.

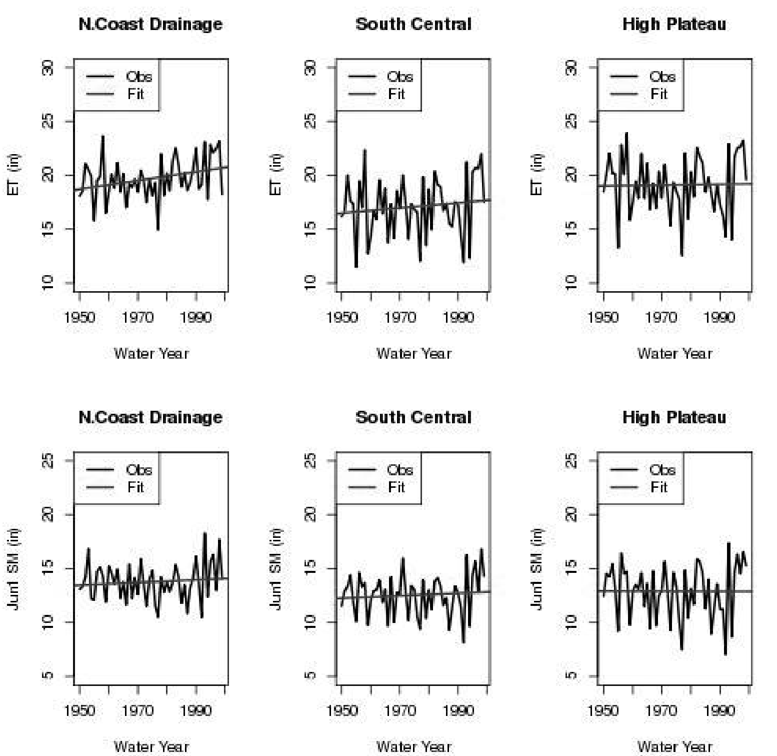
Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent, with a range of 4 to 22 percent depending on the climate division (see Figure 3-8 and Table 3-3). Mayer and Naman (2011) reported larger declines in streamflow over the 1961–2009 period (16 to 38 percent), albeit over spring and summer months only. None of the computed trends in runoff (regional or basin-wide) are statistically significant at the 95th percentile level.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

Figure 3-8. Trends in mean annual water balance parameters (April 1 SWE, annual runoff, and irrigation season runoff) over 1950–1999 water years

Evapotranspiration (ET), as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide (see Figure 3-9 and Table 3-3). Portions of the basin within the three dominant climate divisions indicate a range of increase from about 1 percent in the High Plateau region to 11 percent in the North Coast Drainage region. The increase in ET is statistically significant at the 95th percentile level for the North Coast Drainage climate division only.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

Figure 3-9. Trends in mean annual water balance parameters (annual evapotranspiration and June 1 soil moisture) over 1950–1999 water years

Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole, yet the trends by climate division range from a decrease of about 0.3 percent in the High Plateau region to an increase of 5 percent in the South Central region and an increase of 4 percent in

the North Coast Drainage region (Figure 3-9 and Table 3-3). These trends are not statistically significant at the 95th percentile level.

Table 3-3. Mean change over 1950–1999 period (water years) by climate division within the Klamath River Basin and basin wide

	Basinwide		N Coast Drainage		South Central		High Plateau	
Precip	+0.8in	+2%	+1.3in	+3%	-0.1in	+0.5%	-0.03 in	-0.1%
Tavg	**+1°F**	**--**	**+1.0°F**	**--**	**+1.4°F**	**--**	**+0.8°F**	--
April 1 SWE	-2.0in	-41%	-2.3in	-45%	-1.6in	-42%	-1.0 in	-22%
Annual Runoff	-0.5in	-7%	-0.5in	-6%	-0.6in	-22%	-0.1 in	-4%
Apr-Sep Runoff	-1.2in	-18%	-1.6in	-20%	-0.9in	-19%	+0.1in	+2%
Annual ET	+1.5in	+8%	**+2.0in**	**+11%**	+1.2in	+7%	+0.2 in	+1%
June 1 Soil Moisture	0.4in	+3%	+0.6in	+4%	+0.6in	+5%	-0.03 in	-0.3%

Note: Numbers in bold indicate statistical significance of trends at the 95th percentile level.
Precip =mean annual precipitation/ Tavg = mean daily average temperature; SWE = snow water equivalent; ET = evapotranspiration

As previously mentioned, computed trends are highly dependent on the time period over which they are calculated. The primary reason for the dependence on duration is that, coincident with the low frequency trends resulting from human-induced climate change, there are various patterns of natural climate variability. Temporal patterns of climate variability in the Northwest are strongly influenced by variations over the Pacific Ocean, chiefly El Niño/Southern Oscillation (ENSO). ENSO involves linked variations in the tropical Pacific Ocean and overlying atmosphere. During the El Niño phase of ENSO the wintertime jet stream tends to split, with warmer air flowing into the Northwest and Alaska and a southern branch of the jet stream directing unusually frequent and heavy storms toward southern California. During the El Niño winter and spring, Oregon's climate is slightly more likely than usual to be warm and dry. The Pacific Decadal Oscillation (PDO) is another pattern of climate variability that acts similarly to ENSO, but typically over longer time frames (on the order of multiple decades). Depending on the time period chosen for trend analysis, patterns of natural climate variability may mask or

Historical Surface Water Availability

Of historical precipitation, temperature, snowpack, runoff, evapotranspiration, and soil moisture, the only statistically significant trends at 95th percentile level are:

Temperature (all regions) and evapotranspiration (North Coast Climate Division).

amplify the apparent trends due to human-induced climate change. Choosing longer time periods over which to compute historical trends can help to reduce the relative influence of natural climate patterns on the computed trends.

3.4 Historical Groundwater Availability

For analysis of groundwater impacts of climate change, outputs from surface water hydrology simulations, informed by climate projections, may be used as inputs to groundwater models. For the Klamath River Basin Study, groundwater hydrology is simulated using the USGS MODFLOW, or moderate finite-difference flow model, over the Upper Klamath Basin (upstream of Iron Gate Dam), developed through studies by Gannett et al. (2007, 2012). This model simulates evapotranspiration, groundwater head, and discharge to streams, among other things. Groundwater hydrology is also simulated in the Scott and Shasta Valleys using a multiple regression-based tool. This groundwater simulation tool performs an overall water balance to simulate relative groundwater levels. This modeling tool may be used to evaluate projected changes in the overall water balance of these river systems, as well as to evaluate the effects of projected changes in streamflow on the groundwater system.

3.4.1 Previous Studies

Groundwater modeling studies have been previously conducted for parts of the Klamath River Basin including the Upper Klamath Basin (Gannett et al., 2007, 2012) and the Scott River Valley (S.S. Papadopulos & Associates, Inc., 2012). Additional groundwater modeling efforts are currently underway, including research studies in the Scott and Shasta Valleys by faculty and graduate students at the University of California at Davis (Harter and Hynes, 2008). These studies are further described below.

3.4.1.1 Upper Klamath Basin

Gannett et al. (2007, updated in 2010) completed a groundwater investigation of the Upper Klamath Basin, upstream of Iron Gate Dam, to improve understanding of the groundwater dynamics in the region. The investigation was based on collected data, monitoring, and analysis. Since 2001 the basin has experienced increased groundwater pumping, particularly within and near Reclamation's Klamath Project, in response to various biological opinions and court orders. A water bank program administered by Reclamation, as well as subsequent Klamath Water and Power Agency Water Use Management Plans, have purchased varying quantities of groundwater to supplement surface water in 8 of the past 11 years (2003 through 2013). The water bank provided incentives for irrigators to increase groundwater pumping during years of low surface water availability as a pathway for retaining greater instream flows.

In a subsequent study by Gannet et al. (2012), in collaboration with the OWRD and Reclamation, a MODFLOW finite-difference groundwater model was developed to represent the system and to improve understanding of the long term

effects of the above-described water banking program. In this investigation, the authors sought to identify the optimal strategy for meeting user needs while not exceeding defined impact constraints. This study found that some supplemental groundwater pumping could occur while not exceeding defined constraints, and that groundwater levels should recover from the observed declines if pumping was reduced to pre-2001 rates.

3.4.1.2 Scott Valley

A groundwater study for the Scott Valley (tributary region to the Klamath River, see Figure 3-13) was completed by S.S. Papadopulos & Associates, Inc. in 2012 for the Karuk Tribe. The study examined the impacts of groundwater pumping on the aquifer and on the Scott River by evaluating groundwater levels under three scenarios including recent use conditions, an alternative water use condition representing partial build-out of the existing groundwater capacity, and partial build-out with gradual increases in pumping levels.

Results from the study indicated that long-term declines in groundwater levels were minimal in winter and greater in late summer, corresponding with seasonal groundwater pumping. The declines can, and have, impacted streamflows. The model was used to develop a relationship between groundwater levels and stream depletions, showing that increases in groundwater pumping result in reductions in streamflow mostly within the first year or two (S.S. Papadopulos & Associates, Inc., 2012).

Researchers at the University of California, Davis completed the Scott Valley Community Groundwater Study Plan (Harter and Hynes, 2008, hereafter referred to as the UC Davis Groundwater Study Plan), which discusses the motivation for the approach of their ongoing groundwater modeling study for the Scott Valley. The study is being conducted in cooperation with Siskiyou County and Scott Valley stakeholders as a result of recommendations made in the TMDL Action Plan (State of California, 2005) and the Scott River Watershed Council Strategic Action Plan (Scott River Watershed Council, 2005). The State of California has determined that the water quality standards for the Scott River are exceeded due to excessive sediment and elevated water temperature. Studies on which the TMDL Action Plan is based state that groundwater inflows are a primary driver of stream temperatures in the Scott Valley, along with human-caused changes in riparian shading.

The UC Davis Groundwater Study Plan identifies a number of statements, hypotheses, and research questions that will be addressed during the study. A couple of noteworthy statements include: (1) there is a statistically significant correlation between SWE, total annual precipitation, and average Scott Valley groundwater table elevation in subsequent months/years, and (2) the magnitude and dynamics of seasonal and intra-annual groundwater level fluctuations have significantly changed since 1950.

The S.S. Papadopulos & Associates (2012) modeling study and the ongoing UC Davis groundwater study rely on a survey of geology and groundwater features of the Scott Valley conducted by the USGS in 1958 (Mack, 1958). The report describes in detail the geologic features in the basin and points out some interesting features of the groundwater system. Most of the wells in the area are shallow dug wells, averaging about 25 feet. Recharge to groundwater comes in the form of rainfall, seepage from tributary streams, and irrigation. Losses from groundwater come mainly in the form of evapotranspiration and hyporheic flow into the Scott River. Mack estimated the storage capacity in the flood-plain sediments to be about 220,000 acre-feet. As part of the Mack (1958) study, a number of groundwater level measurements were made either from existing or installed monitoring wells. A number of these wells continued to be used as monitoring wells. These data serve as a primary data source for subsequent Scott Valley groundwater modeling studies, including the current study presented in this chapter.

3.4.2 Approach – Upper Klamath Basin

Groundwater in the Upper Klamath Basin is being simulated using the USGS MODFLOW finite-difference model developed by Gannett et al. (2012). Details of the model configuration may be found in the mentioned study; however, a general discussion is included here. Emphasis in this discussion is placed on two elements of the model with direct linkages to the surface water hydrologic model developed over the region (VIC). The approach discussed below helps to provide context for the approach of evaluating the impacts of projected climate.

The MODFLOW model developed for the Upper Klamath Basin has 100,070 active cells and a historical simulation period of water years 1970 through 2004 (October 1969–September 2004). For the purposes of this study, and to maintain consistency with datasets used to evaluate surface water supply, the historical period was modified to water years 1970 to 1999. The model has quarterly stress periods (every 3 months) and each stress period is divided into five equal timesteps. Model input data are developed on a quarterly basis (i.e., disaggregation to individual timesteps occurs internally within the model).

The MODFLOW model utilizes a number of packages that help to improve its representation of physical processes. The packages implemented in this configuration include the recharge package, well package, stream package, general head boundary package, evapotranspiration package, drain package, and reservoir package, in addition to the basic package. There are two primary linkages with surface water inputs, such as outputs from the VIC surface water hydrologic model. First, VIC model precipitation inputs are used to develop seasonal relationships between precipitation and recharge, which are later used to develop scenarios of future recharge based on projected precipitation. Second, VIC simulated potential evapotranspiration (PET) and actual ET are used to compute the upper threshold for ET used by the MODFLOW model (computed as the difference between PET and actual ET). The modeling study conducted by

Gannett et al. (2012) relied on surface water inputs from the USGS Precipitation Runoff Modeling System (PRMS), developed over the same region.

Assessment of historical groundwater levels in the Upper Klamath Basin primarily comes from the modeling efforts by Gannett et al. (2012). However, as part of the assessment of groundwater supplies, the MODFLOW model was rerun over the modified historical period and is the baseline for comparison of projected groundwater levels.

3.4.3 Present Availability and Historical Trends – Upper Klamath Basin

Present availability and historical trends in groundwater elevation and recharge are discussed in the context of previously completed work by Gannet et al. (2012). The historical MODFLOW simulation described by Gannett et al. (2012) was used as the historical baseline for the assessment of groundwater in the Upper Klamath Basin for this water supply assessment.

Historical availability of groundwater is presented in this section with respect to recharge and groundwater elevations. Historical recharge to the groundwater system was developed by Gannett et al. (2012) using summed subsurface flow (interflow) and groundwater flow terms from the PRMS model. Subsurface (interflow) generated by PRMS represents shallow rapid subsurface flow, which is not well simulated by MODFLOW. Therefore, adjustment factors were applied to the summed recharge values to more accurately simulate recharge in the basin. The resulting historical recharge used as input to the MODFLOW model is illustrated by Figure 3-10.

The highest recharge, according to Figure 3-10, is along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains. The lowest recharge amounts are in the central and southern parts of the basin. It should be noted that amount of recharge does not necessarily correspond to areas with highest ground permeability. Discussions from Section “Upper Klamath Groundwater Basin”, addressing groundwater characteristics of the basin, indicate that the western part of the basin is generally characterized by low permeability, while parts of the central basin are characterized as having high permeability and high groundwater yield. Greater recharge occurs along the western boundary primarily due to the fact that there is more water available for recharge, compared with the central portion of the basin.

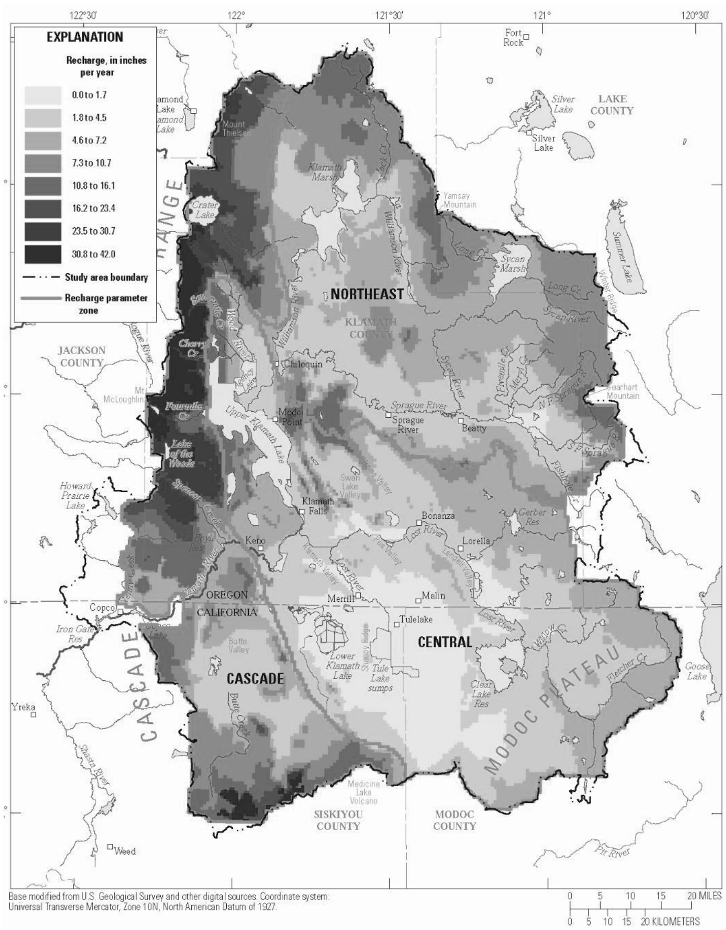


Figure 7. Estimated mean annual groundwater recharge from precipitation in the upper Klamath Basin, Oregon and California, 1970–2004, in inches, and recharge parameter zones.

Source: Figure 7 from Gannet et al., 2012

Note: Recharge Zone 1 (Cascade) lies along the western boundary of the basin. Recharge Zone 2 (Northeast) covers the northeastern part of the basin. Recharge Zone 3 (Central) covers the central and southeastern part of the basin.

Figure 3-10. Summary of mean annual recharge over the Upper Klamath River Basin

Gannett et al. (2012) also summarizes historical simulated groundwater elevations, compared with observations, for a number of sites throughout the Upper Klamath Basin model domain. We provide a sample of figures for two sites, including the Wood River sub-basin, located upstream of Upper Klamath

Lake (Figure 3-11) and the Lower Klamath Lake sub-basin, located in the southcentral portion of the model domain (Figure 3-12).

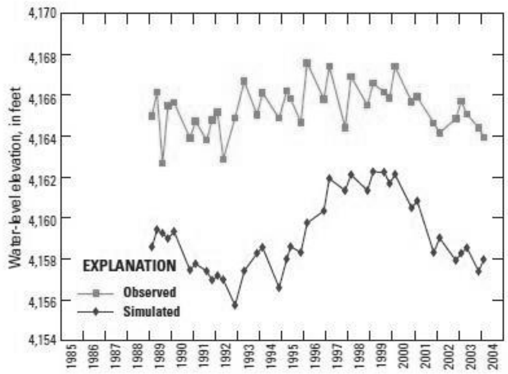


Figure 18. Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

Source: Figure 18 from Gannett et al., 2012

Figure 3-11. Observed and simulated water-level elevations in the Wood River sub-basin

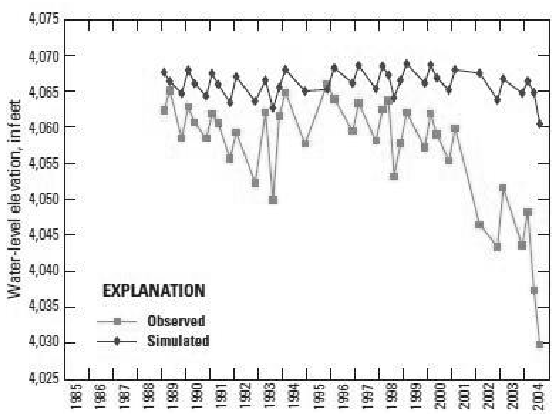


Figure 36. Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

Source: Figure 36 from Gannett et al., 2012

Figure 3-12. Observed and simulated water-level elevations in the Lower Klamath Lake sub-basin

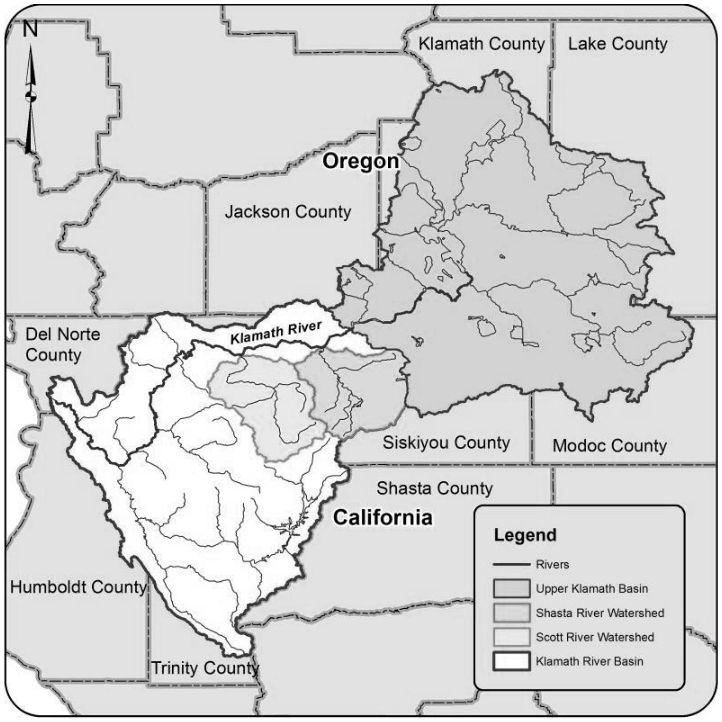
Results for these two sites are representative of the types of calibration results for the MODFLOW model. In general, the model captures the low frequency variability in groundwater levels over the period from the late 1980s through 2004. The model is also able to capture much of the year-to-year variability in groundwater levels. The difference between simulated and observed groundwater elevations can vary from on the order of 5 feet to 30 feet, depending on the site and year. Gannett et al. (2012) suggest the larger differences (seen in parts of the Wood River sub-basin as shown on Figure 3-11, for example) may be due to the coarse vertical discretization of the model, relative to the gradients of groundwater flow. Also for the Lower Klamath sub-basin site (Figure 3-12), the model is not able to capture the decline in observed groundwater elevation that occurs after about 2000 (corresponding with drought and increases in pumping). Differences between observed and simulated groundwater elevations may be attributed, at least in part, to lack of accurate information on rates and locations of pumping in some parts of this sub-basin (Gannett et al., 2012).

Historical Groundwater Availability – Upper Klamath Basin

The highest recharge to groundwater occurs along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains, while the lowest recharge amounts are in the central and southern parts of the basin.

3.4.4 Approach – Scott and Shasta Valleys

The groundwater portion of the Klamath River Basin Study water supply assessment consists of analysis for three main regions within the Klamath River Basin: the Upper Klamath Basin, the Scott Valley, and the Shasta Valley (see Figure 3-13). These regions represent the majority of groundwater use in the Klamath River Basin, as inferred from defined groundwater regions from California’s Groundwater Bulletin 118 (CDWR, 2003). To the extent possible, these analyses rely on existing modeling tools and data.



Sources: Principal Aquifers, http://www.nationalatlas.gov/mld/aquifrp.html; Scott and Shasta Valley Well Data, http://www.water.ca.gov/waterdatalibrary/groundwater/index.cfm.

Figure 3-13. Map of modeled groundwater basins within the Klamath River Basin

Existing groundwater modeling tools for the Scott and Shasta Valleys were explored in the preparation of this water supply assessment. No existing groundwater modeling tools were identified for the Shasta Valley, although there are ongoing studies at the University of California at Davis related to groundwater dynamics of the Shasta Valley.[3] There is also an existing draft groundwater data needs assessment developed by CDWR which has not been finalized (CDWR, 2011). The existing groundwater model for the Scott Valley, developed by S.S. Papadopulos & Associates, Inc. (2012) for the Karuk Tribe, was explored for possible use in the Klamath River Basin Study. However, use of this modeling tool was deemed infeasible due to the reasons outlined below:

[3] http://hsgg.ucdavis.edu/research/student-abstracts/

1. The modeling tool was not readily available for use by Reclamation. In other words, additional funding would have been required to either contract with S.S. Papadopulos & Associates, Inc. to participate in the study or fund them to package the model for use by Reclamation staff.
2. The model was designed with a relatively narrow focus on the impact of groundwater pumping on streamflows.
3. Confidence in the results from a sophisticated MODFLOW finite-difference groundwater model for the Scott Valley, where input data are limited, was not high enough to justify the cost of its implementation in the study.
4. The spatial resolution of the surface water hydrologic model that provides surface water inputs to the groundwater model is coarse in comparison with the size of the Scott River Basin, which also limits confidence in the utility of applying a sophisticated MODFLOW model in the basin.

Conceptual regression-based groundwater screening tools were developed for both the Scott and Shasta Valleys based on the approach taken by Reclamation (2013) in the Santa Ana Watershed Basin Study. The added advantage of developing these tools is consistency in the approach for the two neighboring watersheds. This section briefly describes the groundwater screening tool as it was applied in this Klamath River Basin Study. Details regarding data used as input to the Scott and Shasta Valley tools are described in Appendix B, Supplemental Information for Assessment of Water Supply.

The regression-based groundwater model relies on historical inflows and outflows from the groundwater system, estimated from available data, including spatially distributed recharge from precipitation, focused recharge from stream and canal seepage losses or deep percolation of irrigation water, groundwater abstraction by pumping, and other inflows and outflows. The model is calibrated and verified with respect to available observations. The model may then be applied using projected future conditions, as well as applied management alternatives, to evaluate the effects of climate change and adaptation strategies on groundwater resources.

The groundwater screening tool estimates fluctuations in basin-scale groundwater levels in response to natural and anthropogenic drivers, including climate and hydrologic conditions, agricultural land use, municipal water demand, and trans-basin water imports, if applicable. The tool allows users to quickly estimate basin-scale groundwater conditions under a broad range of future scenarios and provides insight into the primary factors driving basin-scale groundwater fluctuations.

This screening tool is based on a conceptual model which considers fluctuations in basin-average groundwater elevations as a function of basin-scale drivers.

These drivers are illustrated in Figure 3-14 and may be categorized by the following: water availability (precipitation, local streamflow, and trans-basin imports), water demand (municipal and industrial demand, agricultural land use, and evaporative demand), and an optional exogenous input that represents groundwater management objectives that affect basin-scale groundwater levels. As a result, use of the groundwater screening tool does not require detailed information regarding local hydrologic, geologic, climatic, and anthropogenic factors that may affect local groundwater fluctuations. However, it should be noted that as a result of this basin-scale approach, the groundwater screening tool is primarily applicable at the scale of individual groundwater basins or sub-basins, where the effects of local-scale conditions are largely averaged out and where subsurface inflows and outflows from surrounding areas are negligible.

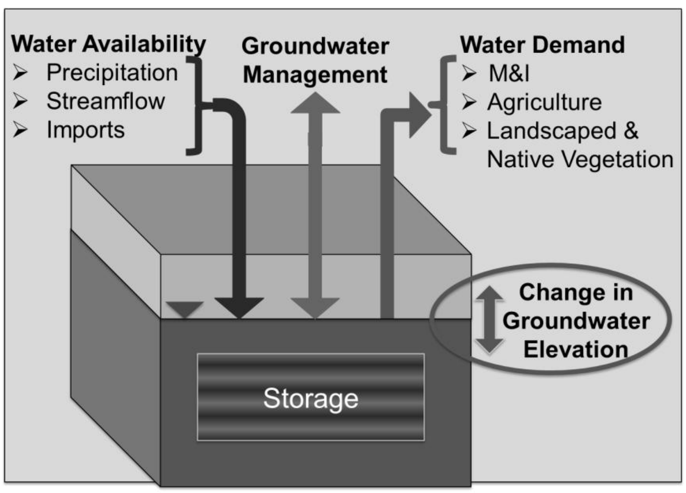
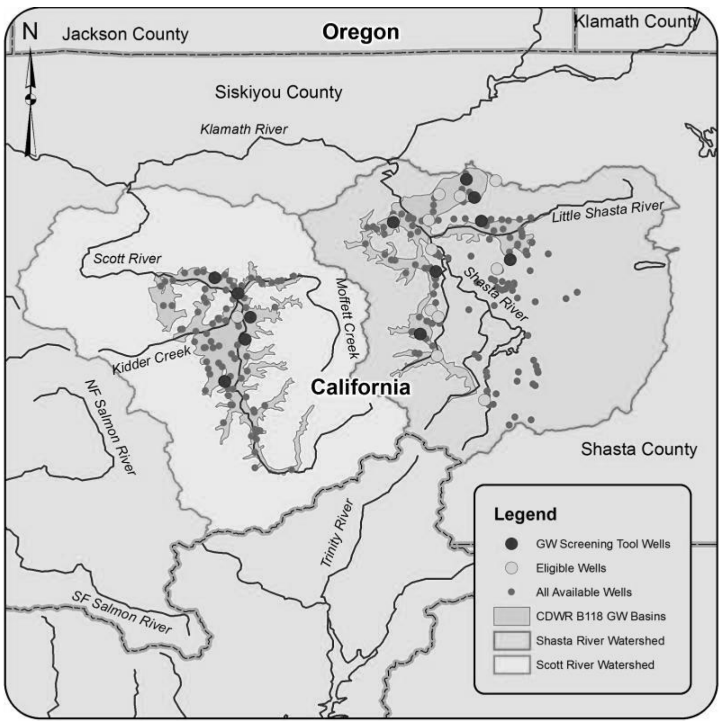


Figure 3-14. Conceptual model of basin-scale groundwater fluctuations used in developing the groundwater screening tool

The model domains for the Scott and Shasta Valleys correspond with groundwater basins defined by CDWR's Bulletin 118 (CDWR, 2003). CDWR Bulletin 118 was first created in the 1950s as a means for collection and evaluation of groundwater data throughout California. Bulletin 118 has been updated numerous times, with the latest update in 2003. Bulletin 118 has defined groundwater basins, including one each for the Scott and Shasta Valleys. Scott and Shasta Valley groundwater basins roughly correspond with the unconsolidated sand and gravel PNW Basin-fill aquifers from the USGS (2003) National Atlas of Principal Groundwater Aquifers[4] map. The Bulletin 118

[4] http://www.nationalatlas.gov/wallmaps.html#aquifers

groundwater basins define the model domain for the groundwater screening tools for the Scott and Shasta Valleys. These groundwater basins are illustrated in Figure 3-15.



Note: The map shows all available wells (grey), eligible wells3 (pink), and wells[3] used in development of the groundwater screening tools for both watersheds (red).

Figure 3-15. Map of CDWR Bulletin 118 groundwater basins for the Scott and Shasta River basins

Historical data were used to determine regression coefficients and to evaluate model performance over the historical period (1980–1999). For this study, historical groundwater elevation data averaged over each groundwater basin were used to fit the regression models. These data came from CDWR and USGS data archives. Monthly mean groundwater elevations were calculated from the available instantaneous measurements. Note that for the Scott and Shasta Valleys, well measurements typically occurred once in the spring and once in the autumn, and interpolated monthly time series were computed from these measurements. Well data were screened for individual outliers and analyzed to determine whether the groundwater elevations at the well are representative of the

average behavior of each groundwater basin (Scott and Shasta). Steps were taken to avoid potential biases due to variations in the period of record between wells, and outlier wells that are not representative of large-scale groundwater fluctuations within a basin. Additional details are provided in Appendix B, Supplemental Information for Assessment of Water Supply, regarding the sources of well data, methods for screening the data, and methods to account for potential biases in well records. Inputs of precipitation, evaporative demand, and streamflow were computed based on VIC model simulations, aggregated to a monthly timestep and averaged over each groundwater basin. Demands such as agricultural and municipal, domestic, and industrial demand were developed based on available data described in detail in Appendix B, Supplemental Information for Assessment of Water Supply. Note that aquifers outside of CDWR Bulletin 118 and well data not archived by CDWR or USGS were not considered as part of this modeling study, which may present limitations in the applicability of the modeling tools to simulate basin-wide behavior.

3.4.5 Present Availability and Historical Trends – Scott and Shasta Valleys

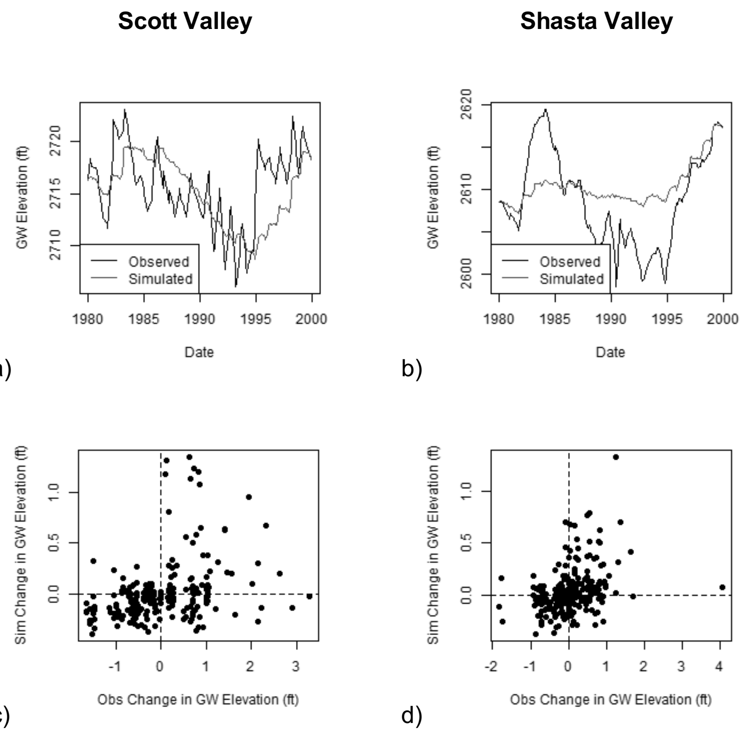
The groundwater screening tool was applied to the groundwater basins in the Scott and Shasta watersheds that were defined by CDWR Bulletin 118 (CDWR, 2003) and are shown on Figure 3-15. There is one defined groundwater basin for each of the watersheds. The screening tools were fit using a linear regression model to the collected observed data (see Equation 1 in Appendix B, Supplemental Information for Assessment of Water Supply). The models were then verified by exploring variations of the groundwater elevation input data. The regressions were tested to ensure that well data used most closely represented basin-wide behavior. Correlations of observed groundwater elevation with individual model inputs were explored and statistically significant correlations (at the 95th percentile confidence level) were found between observed groundwater elevation, precipitation, and runoff for some wells (but not all), indicating that groundwater levels in the Scott and Shasta Valley CDWR Bulletin 118 aquifers are related to climatic fluctuations.

> **Historical Groundwater Availability – Scott and Shasta Valleys**
>
> The statistical groundwater screening tools may be applicable for evaluating the relative impacts of climate change amounts in the central and southern parts of the basin.

Figures 3-16 (a) and (b) illustrate observed and simulated basin-averaged groundwater elevation for the Scott and Shasta groundwater basins, respectively, for the period 1980–1999. The figures show that the groundwater screening tools capture the larger frequency fluctuations (i.e., multi-year trends) in groundwater

elevation, but are not able to resolve finer interannual fluctuations. Both groundwater basins experienced declines in groundwater elevation during the late 1980s and early 1990s on the order of about 20 feet, corresponding with lower precipitation and streamflow during that period. Observed groundwater elevations in the Scott Valley have ranged between about 2,705 feet and 2,725 feet, while observed groundwater elevations in the Shasta Valley have ranged between about 2,600 feet and 2,620 feet. Interannual fluctuations may be driven by local-scale non-linear processes that are not represented in the basin-scale screening tool, or by management activities (for example, pumping) that are not included in this analysis.

Figures 3-16 (c) and (d) illustrate observed change in groundwater elevation versus simulated change in groundwater elevation. They graphically show the data points on which the linear regressions for the groundwater screening tools are based. Model fit statistics summarized in Table 3-4 show that for both the Scott and Shasta Valleys, the screening tools are able to explain a little more than 10 percent of the variance in the data (coefficient of determination, or R^2, of 0.11 and 0.12, respectively, for Scott and Shasta groundwater basins). A more robust model would have higher R^2 values. The degree of model fit indicates that the tool may be applicable for evaluating the relative impacts of climate change, but is not applicable for evaluation of short-term management decisions. In the future, additional and improved data sources may help to improve model fit and thereby the applicability of the tool for a range of purposes.



Note: (a) groundwater elevation for the Scott groundwater basin; (b) groundwater elevation for the Shasta groundwater basin; (c) groundwater elevation change for the Scott groundwater basin; (d) groundwater elevation change for the Shasta groundwater basin

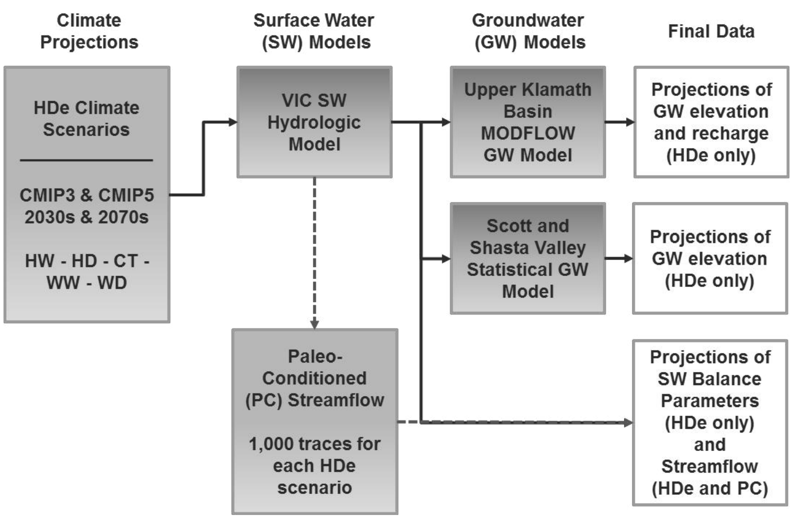
Figure 3-16. Simulated and observed Scott and Shasta basin groundwater elevations, as well as simulated and observed changes in groundwater elevations

Table 3-4. Summary of model fit for Scott and Shasta groundwater basin screening tools

Statistic	Scott Groundwater Basin	Shasta Groundwater Basin
Multiple R2	0.11	0.12
Adjusted R	0.33	0.35
P-value	0.0000511	0.0000101
Residual Standard Error	0.838	0.5905

3.5 Effects of Climate Variability and Change on Supply

This section builds upon tools developed for assessment of historical supplies and provides a detailed discussion of the approach for developing and utilizing future climate scenarios to evaluate projected changes in surface and groundwater. A diagram illustrating the overall approach for evaluating the effects of climate change on water supply is provided in Figure 3-17. Details regarding data linkages between steps are provided in the next section.



Note: HDe refers to ensemble hybrid delta climate scenarios; PC refers to paleo-condition streamflow projections.

Figure 3-17. Summary of approach for evaluating the effects of climate change on surface water and groundwater supplies

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020 through 2049) and 2070s (represented by the mean from 2060 through 2089). In evaluating the effects of climate change on water supply, projections of future supply are commonly compared with that of a historical reference period. The historical reference period for the Klamath River Basin Study is 1970–1999. It should be noted that historical climate has not changed steadily through the 20th century. Basin average temperature has increased from the 1970s through the rest of the century, following an approximate 40-year period of relatively steady temperatures. Basin annual precipitation has fluctuated considerably during the past century, but was relatively steady from the 1940s

through the rest of the century (Reclamation, 2011c). Figure 3-7 illustrates historical trends from 1950 through 1999.

3.5.1 Approach

As a step toward greater understanding of the implications of climate change on the Klamath River Basin, this section first describes the approach for development of climate scenarios for the Klamath River Basin Study water supply assessment, followed by discussions of approaches for evaluation of climate change impacts on surface and groundwater supplies. With respect to surface water, the assessment focuses on projected changes in snowpack, timing and quantity of runoff, ET and soil moisture, and low streamflow periods that have major implications for fish and wildlife and the livelihoods of basin residents. With respect to groundwater, the assessment focuses on projected changes in groundwater recharge and discharge, as well as overall changes in groundwater elevations.

3.5.1.1 Climate Projections

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades as opposed to days or weeks. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings, both natural (such as volcanic eruptions, solar variations) and anthropogenic (such as changing atmospheric composition and land-use change). Climate variability describes deviations from mean climate that may be due to natural internal processes or to variations in natural or anthropogenic forcings. Natural variability includes multi-year cycles in climate such as El Niño and La Niña, as well as cycles that can occur on even longer time scales (for example, the PDO). Changes in climate due to natural variability will continue to occur in the future, along with changes due to increased greenhouse gas concentrations from human activities. Climate change may be differentiated from climate variability as the persistence of anomalous conditions.

> **Climate Projections**
>
> The Klamath River Basin Study utilizes climate projections from World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5).

The state of practice for evaluation of the long-term availability of water supply is to incorporate a range of approaches to characterize past and projected climate. The approaches may include use of paleo-conditioned climate data and use of projections from general circulation models (GCMs). Paleo-conditioned climate data are developed from long-term climatic records (such as tree rings, pollen, etc.) that have been used to capture the natural variability of climate over thousands of years.

Another approach involves downscaling information (in space and time) from native scale GCM resolution to a finer resolution suitable for watershed-scale climate change impact studies. This can be done using dynamical downscaling, which uses GCM output to define boundary conditions for a finer scale regional climate model, or statistical downscaling, which uses historical data as a way of statistically mapping GCM scale information to a finer resolution. Statistical downscaling may involve delta method experiments, which compute period change values based on GCMs and apply them as perturbation factors to historical data. Numerous variations exist within these three categories and there are also approaches that are hybrids of these categories.

The Klamath River Basin Study relies on data and modeling from Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). In that effort, Reclamation developed a consistent database of climate and hydrologic projections, with a focus on the 17 western states that fall within Reclamation's management domain. These projections are based on simulations from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3; Meehl et al., 2007), which are summarized in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007). Projections based on Phase 5 of the same model intercomparison project (CMIP5) reflect improvements in modeling of the Earth system since the CMIP3 effort and revised scenarios of global growth and greenhouse gas emissions. These simulations, which were made available in 2011, are summarized in IPCC's Fifth Assessment Report (Taylor et al., 2012). Both sets of projections, CMIP3 and CMIP5, are utilized as part of the Klamath River Basin Study water supply assessment.

Details regarding the approach for use of climate projections and development of climate scenarios for the Klamath River Basin Study are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, Figure 3-18 illustrates the overall approach for downscaling GCM projections to a finer spatial scale. The figure shows that a similar approach is taken regardless of the choice of CMIP3 or CMIP5 simulations: namely, emissions scenarios are incorporated into GCM simulations. These simulations are bias corrected at the resolution of the GCM and then statistically downscaled to the resolution of the Klamath River Basin Study hydrology models. Bias correction allows for the removal of systematic biases from GCM simulations, based on historical regional climate datasets derived from observations.

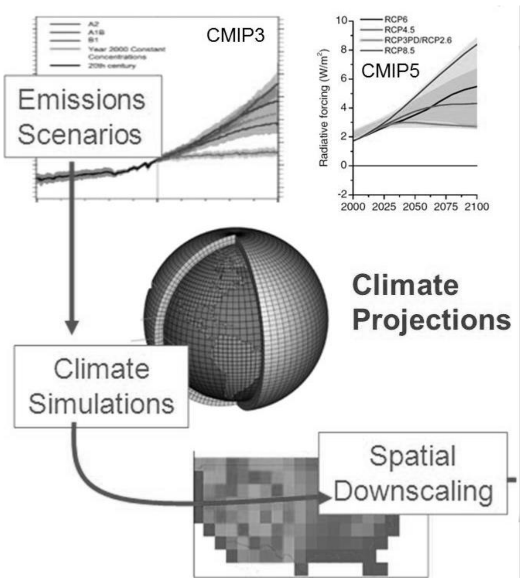


Figure 3-18. Downscaling elements

3.5.1.2 Deriving Climate Change Scenarios from Climate Projections

The high number of climate projections from CMIP3 and CMIP5 (on the order of hundreds of realizations) make their direct use in long term planning studies cost prohibitive in many cases. The Klamath River Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes the available suite of climate projections to derive a smaller number of climate change scenarios to inform long term planning.

The Klamath River Basin Study primarily utilizes climate scenarios that are derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d). The scenarios are developed based on both CMIP3 and CMIP5 statistically downscaled GCM projections, as these are considered equally likely potential climate futures at this time. Details regarding the approach for deriving climate scenarios from CMIP3 and CMIP5 climate projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, a brief overview is provided below.

The hybrid delta method approach for developing climate scenarios involves perturbing historical climate (precipitation and temperature) by change factors computed as the change in precipitation and temperature by month between a chosen future planning horizon and a baseline historical period (Reclamation, 2010). Change factors may be developed for each available downscaled climate projection (CMIP3 or CMIP5) or may be developed based on ensembles of climate projections. The Klamath River Basin Study utilizes an ensemble of climate projections based on both CMIP3 and CMIP5.

HDe Climate Scenarios

Ensemble hybrid delta climate scenarios representing five quadrants of precipitation and temperature change (warm wet, warm dry, central tendency, hot dry, hot wet) are used to encompass a range of possible climate futures for two future time horizons, the 2030s and the 2070s.

The HDe method involves defining a climate change scenario based on pooled information from a collection of climate projections. Use of a sufficiently large number of projections (commonly called an ensemble) pooled together reduces the signal of internal climate variability (which is inherent in each single projection), which may be misinterpreted as climate change. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios. These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT).

Historical precipitation and temperature are mapped, using a quantile mapping technique, onto the bias corrected GCM data to produce a set of transformed observations reflecting future conditions. The entire observed time series of temperature and precipitation at each hydrologic model grid cell is perturbed in this manner, resulting in a new time series that has the statistics of the bias corrected GCM data for the future period, but preserves the time series and spatial characteristics of the gridded temperature and precipitation observations.

The HDe scenarios for the Klamath River Basin Study culminate in a total of 20 scenarios, including two future time horizons (2030s and 2070s), five quadrants of projected change (HW, HD, CT, WW, and WD), and two sets of projections (CMIP3 and CMIP5). Each of these scenarios resemble the historical inputs of daily precipitation and temperature (minimum and maximum) to the VIC surface water hydrologic model in format and period of record because they are all perturbations of historical time series. Windspeed, the remaining required input to the VIC model, was assumed not to change between historical and future time periods. This assumption is in part due to the coarse resolution of historical windspeed data used in the Maurer et al. (2002) historical meteorological dataset

and the associated high level of uncertainty in the data. However, to provide some context, Pryor et al. (2012) found some evidence of lower intense windspeeds in the western U.S. for the 2041–2062 period compared with 1979–2000 from regional climate model simulations.

Figure 3-19 summarizes projected changes in precipitation (a) and temperature (b) by month according to the five HDe climate scenarios for each time period in relation to the full suite of CMIP3 and CMIP5 projections by month. This figure illustrates that the derived climate scenarios generally span the range of projected future precipitation and temperature by the greater number of climate projections. However, with respect to precipitation change, it appears the HDe scenarios project a greater tendency toward increased precipitation during summer months (August, in particular) than the raw climate projections indicate. This is likely due to the fact that the HDe projections are based on projected annual changes in precipitation, not seasonal or monthly changes. Projected annual changes in precipitation appear to be influenced more by increases in winter precipitation.

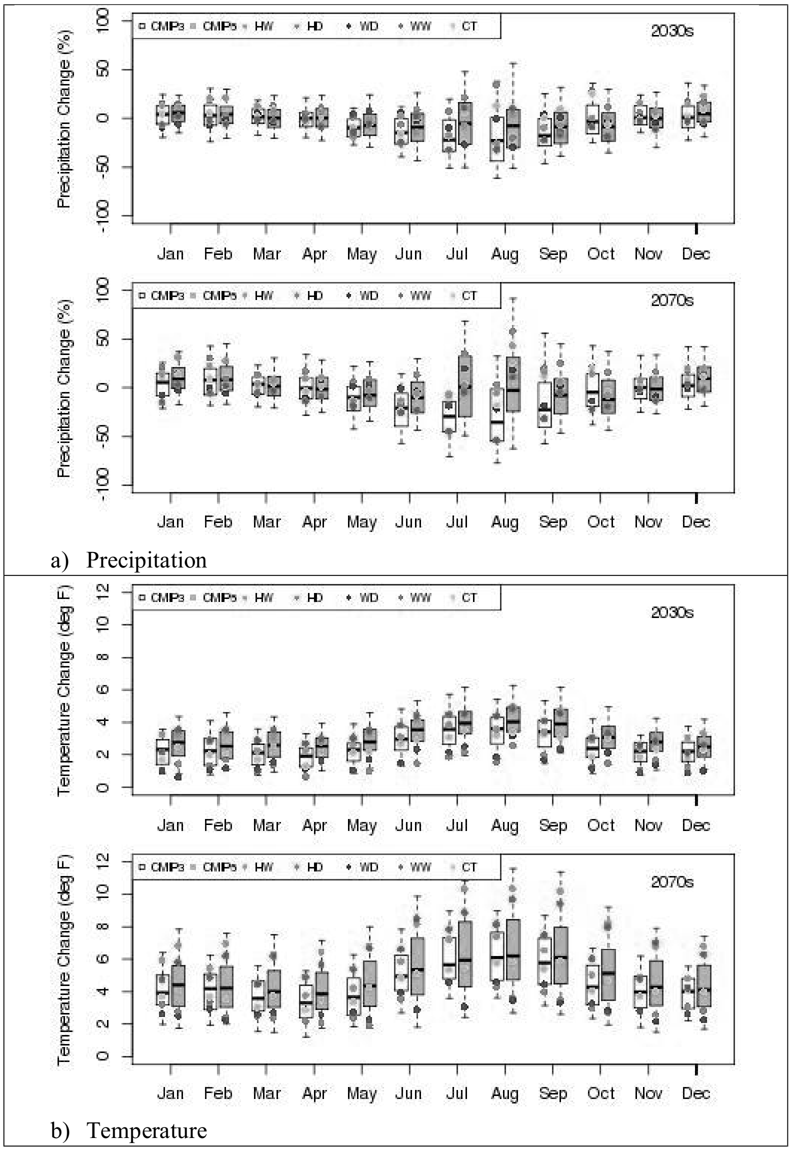


Figure 3-19. Changes in mean monthly precipitation and temperature

HDe scenarios have a number of distinguishing features, with associated strengths and weaknesses. One weakness of this approach is that analysis of climate change impacts is limited to the future time horizons chosen when developing precipitation and temperature change factors. Another weakness is that the scenarios do not incorporate projected changes in drought variability or sequencing of storm events. One key strength of the HDe approach is that the time sequence of projected future storm events matches historical climate data, facilitating direct comparison between the observations and future scenarios. The HDe approach is suitable for water resources planning at both daily and longer time scales, supports analysis of daily hydrologic extremes such as flood and drought intensity, and provides consistency across a range of spatial scales (Hamlet et al., 2010).

3.5.1.3 Deriving Paleo-Conditioned Streamflow Projections

Understanding drought variability is critical to managing water resources across the western U.S. The HDe scenarios described in the previous section may be used as input to surface and groundwater hydrologic models to evaluate changes in the water balance. As mentioned, HDe scenarios are perturbations of the historical record that reflect the statistics of future climate over some chosen time period. As a result, they do not explore the possibility of changes in drought variability (i.e., length or severity of drought periods and wet periods).

Paleo-climate information derived from tree rings or other proxies provides a greater context for sequencing and duration of wet and dry periods than the historical record can provide, often going back hundreds of years. The paleo-conditioned streamflow projections described in this section achieve a blend of projected climate information derived from GCMs and paleo-climate information.

To develop a long-term understanding of drought variability across North America, Cook et al. (2004) developed an extended record of summer time PDSI (Palmer Drought Severity Index) using tree-ring chronologies. This extended PDSI record for North America is available as a gridded (2.5 degrees latitude by 2.5 degrees longitude) timeseries, nearly 200 miles on a side, that dates back nearly 2000 years in some locations. Availability of this extended gridded PDSI record provides an opportunity to analyze regional drought and wet spell characteristics.

For the Klamath River Basin Study water supply assessment, a representative grid location (see Figure 3-20) from the extended gridded PDSI archive was used to analyze long-term wet and dry spells in the Klamath River Basin. Adjacent grid locations provided similar results. The specific location of the PDSI grid used has a center with latitude 42.5 degrees N and longitude 120.0 degrees W., shown by a green triangle in Figure 3-20. The PDSI time-series used from this grid extended from 1400 through 1999.

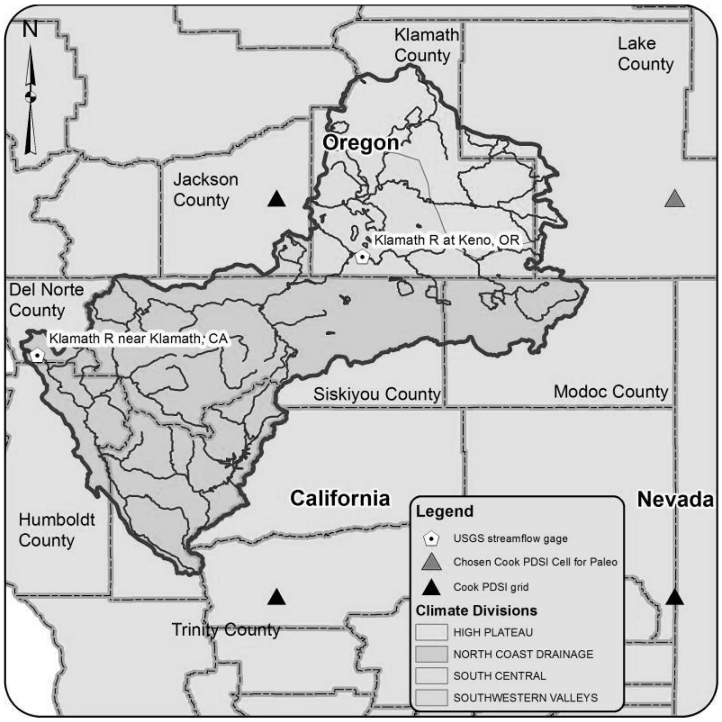


Figure 3-20. Overview map of the Klamath River Basin with Cook PDSI grid and two USGS streamflow gages used in the analysis of paleo-hydrology: Klamath River near Klamath, CA and at Keno, OR

To understand the time-varying nature of wet and dry spells, the PDSI index can be used to determine the probability of regional hydrology shifting from one state to another. In this study, the Klamath River Basin was defined to be either in dry state when the summer time PDSI value in a given year was less than 0 (negative PDSI corresponds to dry conditions), or in a wet state when PDSI was greater than 0 (positive PDSI values correspond to wet conditions). Based on the defined states, probabilities may be derived for the likelihood of transitioning from one state to another. Flow magnitudes can be assigned based on the probabilities, which allows for evaluation of historical streamflow over the instrumental record and projected streamflow compared with the paleo period.

The results for the Klamath River indicate that paleo-conditioned historical simulations show reduced lengths and volumes of wet periods. Results also show droughts of reduced length and deficit, demonstrating that just changing the ordering of flows over the historical period results in periods of both reduced droughts and surpluses. Furthermore, the wet period volumes could be quite a bit lower than what has been historically available, according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than is shown in the recent instrumental record.

Paleo-Conditioned Streamflow Projections

Wet period volumes could be quite a bit lower than what has been historically available according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than what is shown in the recent instrumental record.

Paleo-conditioned streamflow projections are not carried throughout the Klamath River Basin Study water supply assessment and subsequent phases of the Basin Study for two primary reasons. First, analysis of paleo-conditioned streamflow, including historical and HDe scenarios, suggests that periods of drought and surplus over the paleo record are within the range of variability experienced for the historical 1950–1999 period. Thus, including paleo-conditioned projections of streamflow, and potentially other variables, would be computationally time-intensive yet would not yield additional information. Second, because the Klamath River Basin lacks an integrated surface water – groundwater model, there would be inconsistencies in data linkages between models that make use of paleo-conditioned projections infeasible. For example, the groundwater models rely on inputs of climate, recharge, and streamflow, yet paleo-conditioned projections of climate and water balance variables do not exist to correspond with the paleo-conditioned streamflow projections. Paleo-conditioned streamflow projections may provide a greater context for future water supply projections, but are not directly used in further analysis.

3.5.1.4 Surface Water Hydrology

Assessment of climate change impacts on surface water supply was conducted using HDe (ensemble informed hybrid delta) scenarios and was informed by paleo-conditioned streamflow projections. The overall approach is described below and is illustrated in an overview diagram in Figure 3-21.

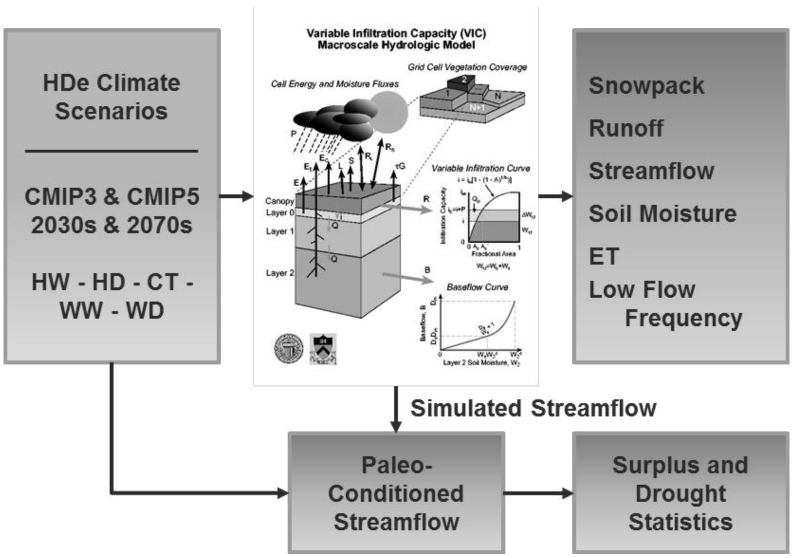


Figure 3-21. Approach for assessment of projected surface water supplies

HDe scenarios may be directly used by the VIC model to generate associated projections of snowpack, runoff, and other elements of the water balance. In evaluating the implications of climate change, the water supply assessment first provides comparisons of results based on CMIP3 and CMIP5 projections with respect to mean annual precipitation and temperature, April 1 SWE, and mean annual runoff.

Following the comparison of CMIP3 and CMIP5 results, the assessment discusses projected changes in seasonal precipitation and temperature, snowpack on April 1, mean annual runoff, spring runoff, June 1 soil moisture, mean annual ET, mean monthly streamflow at select sites, annual runoff timing, and changes in the 7 day low flow with 10 year recurrence interval (also called 7Q10). This part of the assessment focuses on results using CMIP5 projections (unless otherwise noted) for the two future time horizons (2030s and 2070s); however, figures based on CMIP3 projections, corresponding to those presented in the water supply assessment, are presented and briefly discussed in Appendix B, Supplemental Information for Assessment of Water Supply.

Drought and surplus statistics are evaluated based on the developed paleo-conditioned streamflow traces. Paleo-conditioned streamflow relies on projected natural streamflow output from the VIC model as well as statistics developed from the analysis of the paleo-record. Projected natural streamflows from the VIC model are resampled 1,000 times for each of the five HDe climate change scenarios, future time horizons, and projection types (CMIP3 and CMIP5) to develop statistics of projected surplus and drought volumes and lengths.

3.5.1.5 Groundwater Hydrology

This section describes the approaches for utilizing climate change scenarios to evaluate projected changes in groundwater recharge, discharge, and elevations in three groundwater basins of the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys.

Upper Klamath Basin

The effects of projected climate on groundwater in the Upper Klamath Basin were analyzed using the existing MODFLOW finite-difference groundwater model developed by Gannett et al. (2012). For this study, the model was driven by HDe climate scenarios and surface water hydrologic projections, and results were compared with the historical simulation (presented and summarized in Section 3.4.3, Present Availability and Historical Trends – Upper Klamath Basin) to evaluate results due to changes in climate alone, excluding any impact due to changes in groundwater demand (i.e., pumping). Paleo-conditioned streamflow projections were not taken through the Upper Klamath Basin groundwater impacts analysis because stream stages are held constant in the MODFLOW simulations and Gannett et al. (2012) determined that streams generally have very little net exchange with the groundwater system. The avenues for incorporation of projected surface water inputs into the MODFLOW model are listed below, and they do not have associated paleo-conditioned projections.

1. Projected maximum ET for each of the five HDe climate change scenarios, where maximum ET is represented as PET less actual ET as computed from VIC surface water hydrology model output
2. Projected groundwater recharge for each of three recharge zones for each of the five HDe climate change scenarios

The methodology for developing each type of projected MODFLOW input is described briefly below and illustrated in an overview diagram in Figure 3-22.

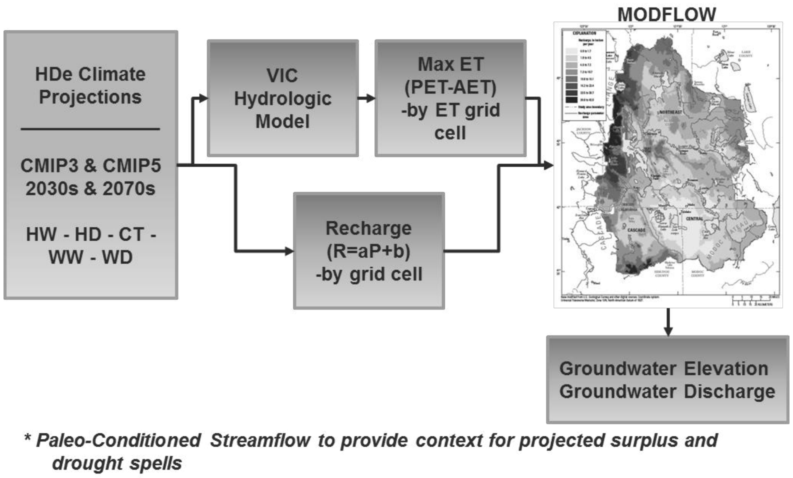


Figure 3-22. Approach for assessment of projected groundwater supplies in the Upper Klamath Basin

Maximum Evapotranspiration Rate

Evapotranspiration is modeled in the Upper Klamath Basin MODFLOW model (Gannett et al., 2012) using the EVT, or evapotranspiration package. One of the principal input parameters is the maximum ET rate associated with groundwater. Gannett et al. (2012) computed this parameter based on output from the PRMS surface water hydrology model. Specifically, this parameter is computed as the difference between PET and actual ET. This difference represents the amount of potential demand that could be supplied by groundwater and is not supplied by precipitation.

In this study, the VIC model was used to generate meteorological inputs for future MODFLOW simulations. The VIC model was chosen, as opposed to PRMS, because it is available for the entire Klamath River Basin, is widely used for studies of climate change impacts, and was used in the hydrologic modeling and development of hydrologic projections as part of Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). Maximum ET was computed on a quarterly (seasonal) basis from VIC simulations for the five HDe climate change scenarios. Quarterly maximum ET computed from VIC simulations (at 1/8th degree spatial resolution) was compared with historical maximum ET used in the historical MODFLOW simulation, aggregated to VIC's spatial resolution. Quarterly (stress period) change factors were developed at the VIC model spatial resolution and factors were applied to historical maximum ET from MODFLOW for each MODFLOW cell within a VIC grid cell. The reason for using change factors and not directly applying projected maximum ET from the VIC model is

to avoid introducing bias due to the differing model constructs (i.e., PRMS generated historical maximum ET while VIC generated projected maximum ET).

Groundwater Recharge
The Gannett et al. (2012) historical groundwater simulation uses as input historical groundwater recharge computed by the PRMS model. Because the VIC model was used to generate inputs for future projection simulations, and because historical simulated recharge from VIC may be quite different from recharge used in the historical MODFLOW simulation (derived from the PRMS hydrologic model), a relationship was developed between historical annual precipitation (gridded dataset developed by Maurer et al. [2002] was used in development of surface water hydrology for this study as well as future climate scenarios) and historical annual recharge.

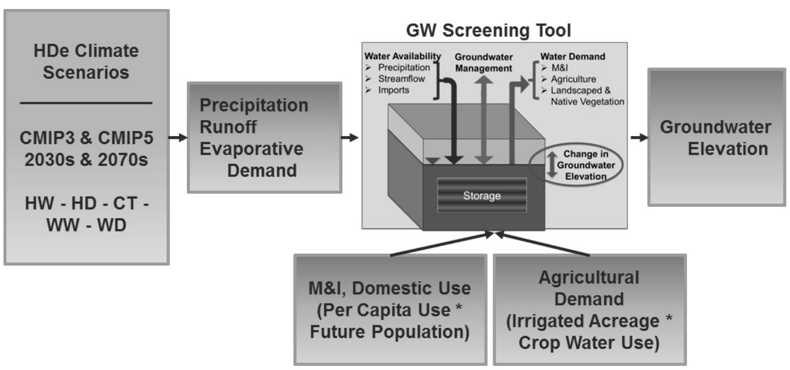
Although alternate relationships were explored in this study, a linear relationship between precipitation and recharge appeared to best represent the data. Such a relationship was developed using annual recharge and precipitation (at the spatial resolution of the VIC model), aggregated by recharge zone. Using the developed relationships between annual recharge and precipitation (by recharge zone) based on historical data, the same relationship was applied to each of the five HDe climate change scenarios of precipitation for two future time periods (2030s and 2070s) and for CMIP3 and CMIP5 projections. As a result, corresponding projections of recharge were developed at the VIC model resolution. These projections were used to generate annual change factors (based on ratios between projected recharge and MODFLOW historical), which were then applied to historical recharge uniformly over all MODFLOW grid cells within a corresponding VIC model grid cell.

Caveats
It should be noted that the described approach for developing projected surface water inputs to the Upper Klamath Basin MODFLOW model may introduce errors in the groundwater balance due to inconsistently developed inputs. For example, recharge and maximum ET projections were developed using established relationships between projections based on HDe scenarios and historical values used in MODFLOW historical simulations. Hence, they were not developed via an integrated surface water model. Despite the use of potentially inconsistent methodologies, this approach provides the best available estimates of projected surface inputs to the groundwater system.

Scott and Shasta Valleys
Projections of future groundwater elevation may be computed for the Scott and Shasta Valleys using the groundwater screening tools developed and described in Section 3.4, Historical Groundwater Availability. Similar to the Upper Klamath Basin, perturbed historical inputs representing projected conditions were used by the models to generate projections of groundwater elevation. Future projections were incorporated for climate and water balance input terms, as well as municipal, domestic, and industrial demand with respect to projected population.

Agricultural demand was left unchanged for the water supply assessment in order to focus on the impacts of climate change on groundwater elevation, and not changes in agricultural demand. Variations in historical agricultural demand are incorporated into historical groundwater elevations used to develop relationships in the computation of groundwater response. However, projected changes in temperature and precipitation will affect agricultural demand, which may markedly affect groundwater levels beyond what was experienced historically. In the discussions of climate change impacts on water demand in the watershed and associated risks and system reliability (Chapters 4 and 5 of this Klamath River Basin Study report, respectively), we address projected changes in agricultural demand and how the watershed may be impacted by the compounded stresses associated with climate change (with and without management adaptations).

Specific projected inputs to the groundwater screening tools for the Scott and Shasta Valleys are further described below. An overview diagram illustrating how projected inputs are incorporated into the groundwater screening tools is provided in Figure 3-23.



** Paleo-Conditioned Streamflow to provide context for projected surplus and drought spells*

Figure 3-23. Approach for assessment of projected groundwater supplies in the Scott and Shasta Valleys

Future projections of monthly mean precipitation and daily mean temperature (surrogate for evaporative demand) computed over the groundwater basins were input to the groundwater screening tools for each basin. These climate scenarios were based on the five HDe climate change scenarios for two future time horizons (2030s and 2070s) as well as for projections based on both CMIP3 and CMIP5. Similar projections of mean monthly runoff over each of the groundwater basins were also input to the models.

It should be noted that the approaches described above for developing projected surface water inputs to the Scott and Shasta Valley groundwater screening tools (including precipitation, temperature, and runoff) are compatible. These inputs rely on HDe climate scenarios themselves (in the case of precipitation and temperature) or outputs generated by the VIC model (runoff) whose simulations rely on HDe climate scenarios.

Municipal, industrial, and domestic water demand, which was computed based on the product of per capita water use and population, was perturbed according to projected population growth. Per capita use was assumed to remain constant. Projected population for each of the two future time horizons (2030s and 2070s) was computed by assuming a percent increase in population equal to the percent change between 1990 and 2000, which was documented by the 2000 Census.[5] For the Scott Valley this was +1.93 percent, while for the Shasta Valley it was +2.01 percent over ten years. The mean of projected population 2020–2050 was used to represent 2030s population, while the mean of projected population 2060–2080 was used to represent 2070s population. Additional scenarios of population growth were not considered as part of the water supply assessment; however, additional scenarios may be considered in subsequent stages of the Klamath River Basin Study as part of the analysis of management alternatives and/or adaptation strategies.

As previously mentioned, agricultural water demands were not modified as part of the evaluation of climate change impacts on groundwater elevations in the Scott and Shasta Valleys. The primary reason changes in agricultural demand were not considered here is that detailed analysis of the implications of projected agricultural demand is part of the assessment of current and future water demands in Chapter 4.

3.6 Comparison between CMIP3 and CMIP5

Projections of climate as well as surface water and groundwater hydrologic variables were summarized using both CMIP3- and CMIP5-based projections to understand whether these projections provide a similar view of future conditions. Few studies exist to provide guidance on whether the more recent CMIP5 projections ought to supersede those from CMIP3, whether they are similar enough that one or the other may be used, or whether they ought to be used collectively in impacts assessments. The intent of the Klamath River Basin Study water supply assessment is not to provide such guidance, but instead to evaluate the impacts of climate change using both sources of projections to provide the most comprehensive understanding possible of projected changes in water supply in the watershed.

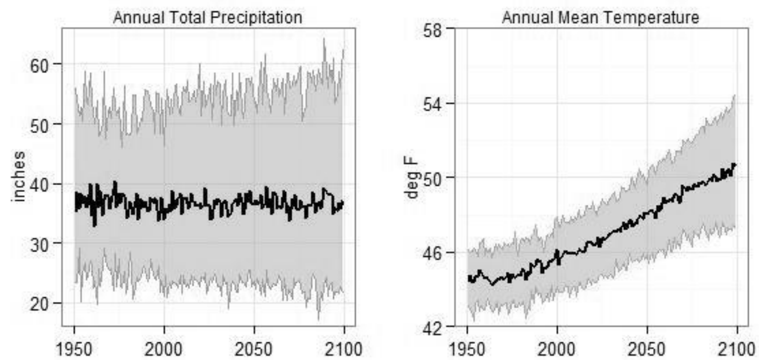
[5] http://www.ncdc.noaa.gov/climate/research/population/

3.6.1 Climate

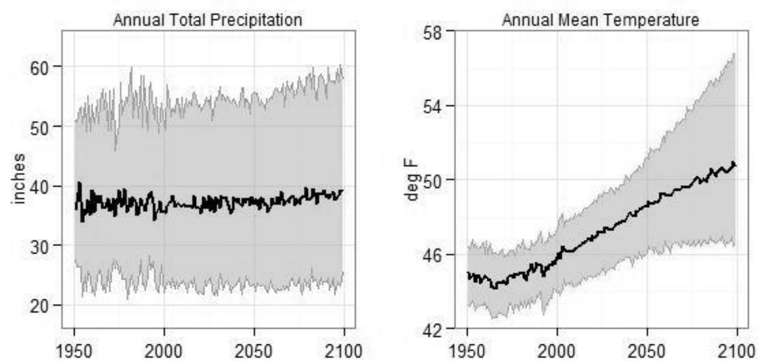
The basis for the five HDe climate change scenarios of precipitation and temperature (minimum and maximum) used throughout the Klamath River Basin water supply assessment is a suite of monthly statistically downscaled GCM simulations, based on CMIP3 and CMIP5 projections. As described in detail in Section 3.5.1.1, Climate Projections, HDe scenarios are generated by computing change factors between designated future time horizons (in this case the 2030s and 2070s) and a designated historical period (in this case 1970–1999).

Figure 3-24 illustrates the envelopes of projected mean annual precipitation and temperature as they evolve through time (i.e., light red on the top panel for temperature and light blue on the bottom panel for precipitation). All projections show that the region will become warmer during the 21st century, with greater uncertainty in annual temperature farther into the future as shown by the widening swath of projections. Annual precipitation in the Klamath River Basin is projected to increase slightly through time. However, it should be noted that this slight projected increase (both for CMIP3 and CMIP5 projections) is within the range of historical variability in precipitation from year to year. In contrast, for temperature, the median projection shows that temperatures will exceed the range of historical year to year variability by about 2050.

A comparison of CMIP3 and CMIP5 projections shows that trajectories through time appear similar; however, the range of projected precipitation is similar between the two types of projections, while projected temperature appears greater with CMIP5 projections. The larger projected range in projected temperature is likely due to the consideration of the full range of emissions scenarios for both CMIP3- and CMIP5-based projections. As shown in Figure 3-24, the range of projected global warming is greater for CMIP5 scenarios than for CMIP3.



a) **CMIP3**



b) CMIP5

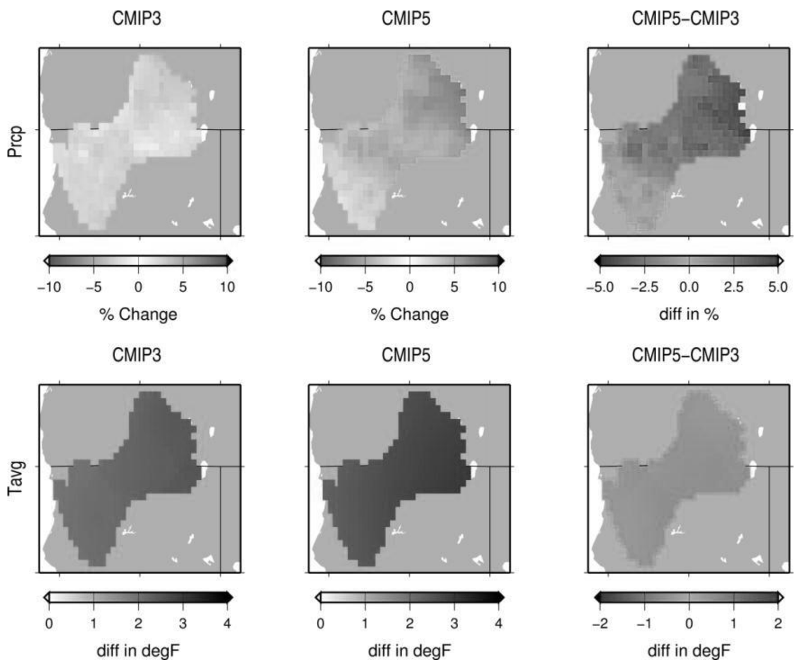
Note: The top row (a) and bottom row (b) illustrate the range of CMIP3 projections and CMIP5 projections, respectively. The black line in each panel shows the median of annual projections, while the colored band represents the range of all GCM projections (112 for CMIP3 and 234 for CMIP5).

Figure 3-24. Summary of statistically downscaled GCM projections of mean annual precipitation and temperature from 1950 to 2100

Figure 3-25 shows projected changes in mean annual precipitation (in percent) and average temperature (in degrees F) for the 2030s, compared with the historical baseline (1950–1999), using both CMIP3- and CMIP5-based HDe scenarios, while Figure 3-26 shows similar projections for the 2070s. It should be noted that these projections do not reflect information from the paleo record, as paleo-conditioned projections only correspond with streamflow. The projections shown in the figures represent the central tendency derived using the HDe approach. Each figure shows projections based on CMIP3 in the left panel,

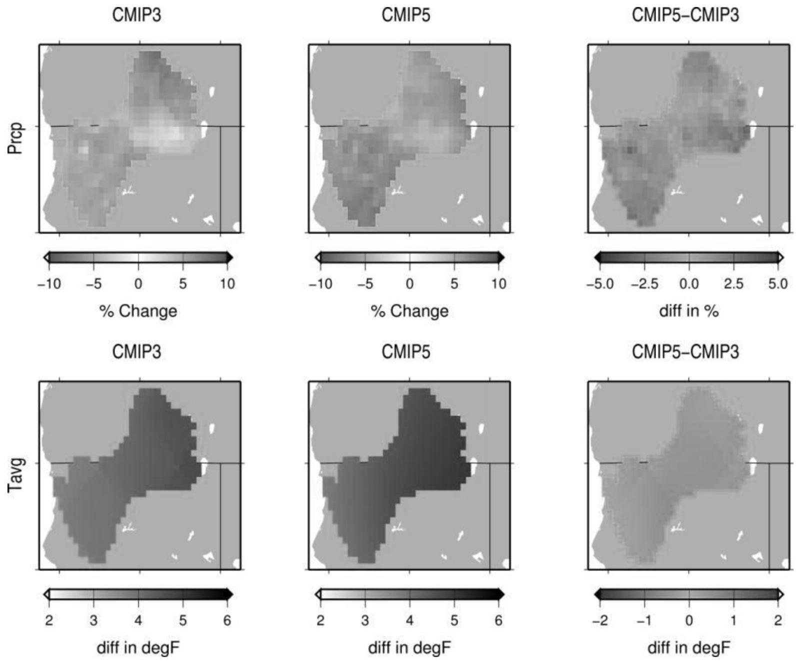
projections based on CMIP5 in the middle panel, and the difference between CMIP5 and CMIP3 in the right panel.

Projected changes in precipitation and temperature are positive for both CMIP3 and CMIP5 for the 2030s and 2070s. As can be seen in Table 3-5, which summarizes spatially averaged projected changes for both time horizons and over three dominant Klamath River Basin climate divisions as well as the basin as a whole, there are notable differences in the magnitude of projected change.



Notes:
1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

Figure 3-25. Comparison of percent change (2030s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5



Notes:
1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

Figure 3-26. Comparison of percent change (2070s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5

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For the 2030s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the North Coast Drainage, which is located at the California portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 4.1 percent increase in mean annual precipitation, while CMIP3-based scenarios indicate a 2.4 percent increase by the 2030s. CMIP5-based scenarios are noticeably wetter than CMIP3 in the eastern portions of the High Plateau and South Central climate divisions. However, CMIP5-based scenarios are noticeably drier in the southernmost portion of the watershed, as previously mentioned. With respect to mean annual average temperature for the 2030s, CMIP5 projections indicate a greater increase in temperature than CMIP3 for all spatial domains considered (see Figure 3-2), although the projections are not substantially different. Projected temperatures basin-wide for the 2030s central

tendency show an increase of 2.2 degrees F for CMIP3 and 2.7 degrees F for CMIP5.

For the 2070s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the High Plateau, which is located at the northernmost portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 6.1 percent increase in mean annual precipitation, while CMIP3 projections indicate a 5.2 percent increase by the 2070s. With respect to mean annual average temperature for the 2070s, CMIP5 projections indicate a greater increase in temperature than CMIP3 projections for all spatial domains, which is similar to results for the 2030s. Projected temperatures basin-wide for the 2070s central tendency indicate an increase of 4.2 degrees F for CMIP3 and 4.5 degrees F for CMIP5.

Although the magnitude differences are quite similar between CMIP3 and CMIP5 for precipitation and temperature for each future time horizon (central tendency), the spatial differences between CMIP3 and CMIP5 are interesting (see the right panels of Figures 3-25 and 3-26). For the 2030s, CMIP3 projections show less increase in precipitation that CMIP5 in the lowermost portion of the Klamath River Basin, while also showing a larger increase in the easternmost portion of the basin. For the 2070s, CMIP3 projections show less increase in precipitation in the Oregon portion of the basin than CMIP5 projections, while in most other parts of the basin CMIP5 projections show greater increase. The spatial differences between CMIP3- and CMIP5-based scenarios may be due to internal variability in the model simulations, and therefore the spatial patterns should be viewed collectively as potential future conditions.

CMIP3 and CMIP5 Comparison – Precipitation and Temperature

Ranges of projected precipitation appear similar while ranges of temperature appear greater with CMIP5 than with CMIP3 scenarios. Spatial differences between CMIP3 and CMIP5 scenarios may be due to internal variability in the model simulations and HDe scenario development. By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

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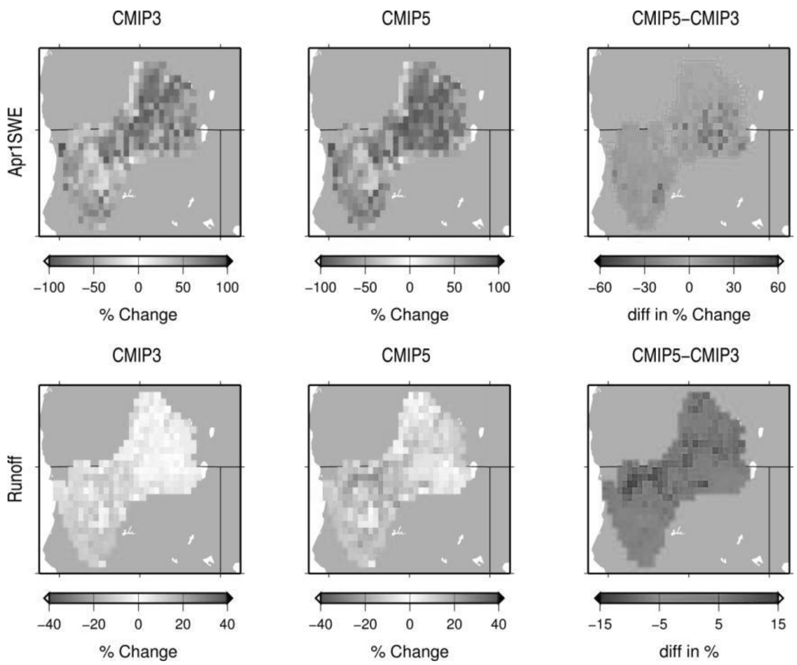
Table 3-5. Summary of projected changes in mean annual precipitation and average temperature for the 2070s, compared with the historical baseline

(1950–1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions

Climate Division	Basinwide	North Coast Drainage	South Central	High Plateau
2030s				
Prcp, CMIP3	+2.4 %	+2.3 %	+2.4 %	+2.7 %
Prcp, CMIP5	+4.1 %	+3.6 %	+5.4 %	+5.8 %
Tavg, CMIP3	+2.2 degF	+2.2 degF	+2.3 degF	+2.4 degF
Tavg, CMIP5	+2.7 degF	+2.6 degF	+2.8 degF	+2.8 degF
2070s				
Prcp, CMIP3	+5.2 %	+5.0 %	+5.1 %	+6.4 %
Prcp, CMIP5	+6.1 %	+6.3 %	+5.3 %	+5.7 %
Tavg, CMIP3	+4.2 degF	+4.1 degF	+4.3 degF	+4.4 degF
Tavg, CMIP5	+4.5 degF	+4.4 degF	+4.7 degF	+4.7 degF

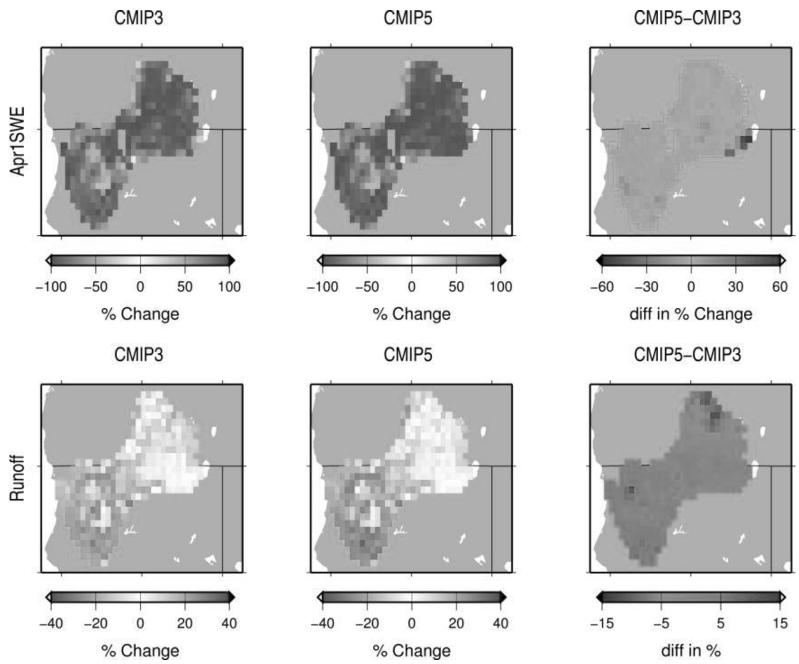
3.6.2 Water Balance

Comparisons of CMIP3 and CMIP5 projections of April 1 SWE and mean annual runoff, both calculated using the VIC model, are illustrated in Figure 3-27 for the 2030s and Figure 3-28 for the 2070s and summarized in Table 3-6. Projections of snowpack on April 1 are presented, in part, because this is a common measure often used in climate change impact studies across the western U.S., but also because historical snowpack is at, or just past, its peak in early April and this measure is often used by water managers as a measure of spring and summer water supply. For the 2070s, CMIP3- and CMIP5-based projections of April 1 SWE show a similar magnitude of change and slight spatial differences (refer to Figure 3-28, upper left and upper central panels). The water balance terms are influenced by changes in precipitation and temperature across the landscape. Although both CMIP3 and CMIP5 projections indicate declines in April 1 SWE by roughly 30 to 40 percent by the 2030s and 60 percent by the 2070s for the central tendency, despite projected increases in annual runoff (see Table 3-5 for computed percent change over the basin and three dominant climate divisions).



Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

Figure 3-27. Comparison of percent change (2030s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios based on CMIP3 and CMIP5



Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

Figure 3-28. Comparison of percent change (2070s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios, based on CMIP3 and CMIP5

For both future time horizons, greater decreases in snowpack are projected for lower elevation regions while mountainous parts of the basin, namely the Cascades and Trinity Alps, show smaller projected decreases in April 1 SWE. Further, for the VIC model pixel that contains Mount Shasta (refer to the white square in the central area of the upper left and upper central panels of Figure 3-27 and Figure 3-28), snowpack is not projected to change substantially, likely due to the combined effects of its relatively high elevation, projected increases in precipitation, and projected increases in temperature.

The upper right panels of Figure 3-27 and Figure 3-28 show the differences in April 1 SWE between CMIP3 and CMIP5 projections. Although differences for the 2030s and 2070s central tendency are small, the CMIP3 projection indicates a larger decrease in snowpack than CMIP5 in parts of the Upper Klamath Basin for the 2030s and the easternmost portion of the basin in California for the 2070s. Smaller differences in April 1 SWE are projected for the 2070s. Mean percent

change in April 1 SWE across the Klamath River Basin is -33.8 percent for the 2030s and -58.2 percent for the 2070s.

Table 3-6. Summary of projected changes in April 1 SWE and annual runoff for the 2030s compared with the historical baseline (1950-1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions

Climate Division	Basinwide	High Plateau	South Central	North Coast Drainage
2030s				
Apr1 SWE, CMIP3	-33.8 %	-38.9 %	-31.0 %	-32.5 %
Apr1 SWE, CMIP5	-39.8 %	-41.4 %	-35.4 %	-39.8 %
Ann Runoff, CMIP3	+7.3 %	+1.4 %	-0.6 %	+8.8%
Ann Runoff, CMIP5	+11.6%	+3.4 %	+4.6 %	+12.9 %
2070s				
Apr1 SWE, CMIP3	-58.2 %	-61.9 %	-54.7 %	-57.3 %
Apr1 SWE, CMIP5	-62.0 %	-65.6 %	-58.8 %	-61.1 %
Ann Runoff, CMIP3	+13.9 %	+0.1 %	-0.5 %	+16.4 %
Ann Runoff, CMIP5	+15.3 %	-5.1 %	-2.5 %	+18.7 %

According to projections based on both CMIP3 and CMIP5 for the 2030s and 2070s, mean annual runoff is projected to increase in the Lower Klamath Basin while changes in the Upper Klamath Basin vary both in magnitude and direction and between CMIP3 and CMIP5 (refer to lower panels of Figure 3-27 and Figure 3-28). Projected changes in runoff based on climate division show increases in the North Coast Drainage on the order of 16 or 19 percent (for CMIP3 and CMIP5, respectively) for the 2070s central tendency and decreases across the South Central climate division on the order of 1 to 3 percent (for CMIP3 and CMIP5, respectively). Across the High Plateau (the region upstream and to the east of Upper Klamath Lake; refer to Figure 3-2), projections are mixed, with CMIP3-based projections indicating a slight increase in mean annual runoff and CMIP5-based projections indicating a decrease in mean annual runoff for the 2070s. The lower right panels of Figure 3-27 and Figure 3-28 illustrate the spatial difference between CMIP3 and CMIP5 for the 2030s and 2070s, respectively. For the 2030s, CMIP5 projections indicate greater changes in runoff over the mainstem Klamath River area than CMIP3, yet smaller changes in runoff over the higher elevation regions of the Trinity River basin and Tule Lake area. For the 2070s, CMIP5 projects lower runoff change than

CMIP3 and CMIP5 Comparison – Water Balance

CMIP3 and CMIP5 water balance projections are largely consistent, indicating decreases in April 1 SWE on the order of 34-40 percent for the 2030s and close to 60 percent for the 2070s, and increases in annual runoff of 7-12 percent for the 2030s and 14-15 percent for the 2070s.

CMIP3 in the Upper Klamath Basin and lower runoff change than CMIP3 in the Lower Klamath Basin.

The differences between CMIP3 and CMIP5 projections for the 2070s central tendency in projected precipitation, temperature, snowpack, and runoff show great similarities in the central tendency scenario for the Klamath River Basin as a whole. However, there are notable differences in that CMIP5 projections tend to be wetter and warmer over the Klamath River Basin than those from CMIP3. Also, there are notable spatial differences that are important to consider when relying on projections from either CMIP3 or CMIP5 (but not both) for water management decision-making.

3.7 Future Availability

Projected availability of surface water and groundwater in the Klamath River Basin was assessed by evaluating changes in seasonal precipitation and temperature, snowpack, timing and quantity of runoff, soil moisture and ET, low flow frequency, and groundwater recharge and discharge. For the most part, this assessment focuses on projections based on CMIP5; however, corresponding results based on CMIP3 projections were also developed and are included in Appendix B, Supplemental Information for Assessment of Water Supply.

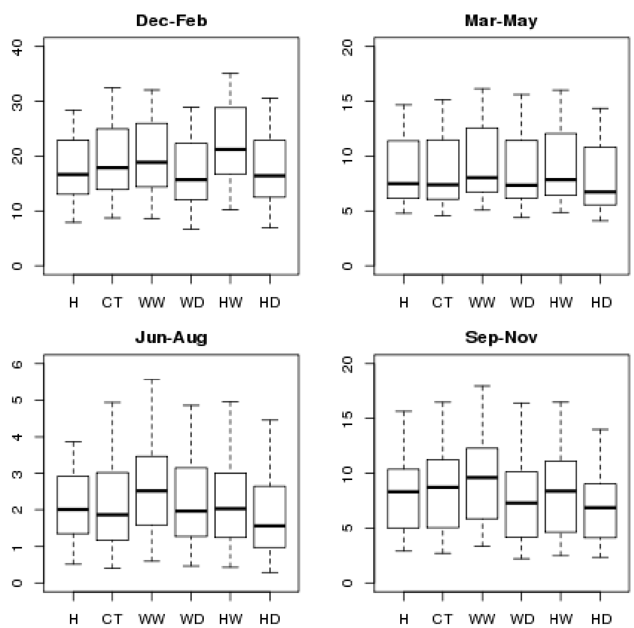
Figure 3-29 illustrates projections of seasonal basin mean precipitation for the 2070s compared with the historical period, based on CMIP5. Each panel includes box plots of historical and projected precipitation, where the boxes represent the 25th, 50th, and 75th percentile values for seasonal precipitation averaged across the Klamath River Basin, and the whiskers represent the 5th and 95th percentile values.

> **Future Availability – Precipitation and Temperature**
>
> Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

In general, the box plots show that the majority of precipitation falls between December and February, an order of magnitude greater than between June and August. In winter (December through February; refer to upper left panel of Figure 3-33), central tendency, WW, and HW scenarios indicate an increase in precipitation, while the WD and HD scenarios indicate decreases in precipitation over this time period. The range between 5th and 95th percentile values across each of the five HDe climate change scenarios appears similar. Projections for the spring period between March and May (upper right panel) and the autumn period between September and November (lower right panel) appear similar to historical conditions, with slight increases for the wetter scenarios (WW and HW) and slight decreases for the drier scenarios (WD and HD). Projections for the summer period (June through August; refer to lower

left panel) show a slight decrease in the median of the central tendency scenarios compared with historical, and decreases in general for the drier scenarios and increases for the wetter scenarios. However, it is notable that the WW scenario indicates a larger increase in summer precipitation than the HW scenario.

It is important to mention that HDe climate change scenarios were developed based on projected changes from multiple GCMs in annual precipitation and temperature across the basin, potentially dampening the signal toward drier summers and wetter winters (as shown in Figure 3-19). Also, the Klamath River Basin water supply assessment does not evaluate projected changes in extreme precipitation events, which are also likely to change as a result of climate change. The focus of this water supply assessment is on the watershed's overall monthly to seasonal water balance, rather than the effects of individual storm events.

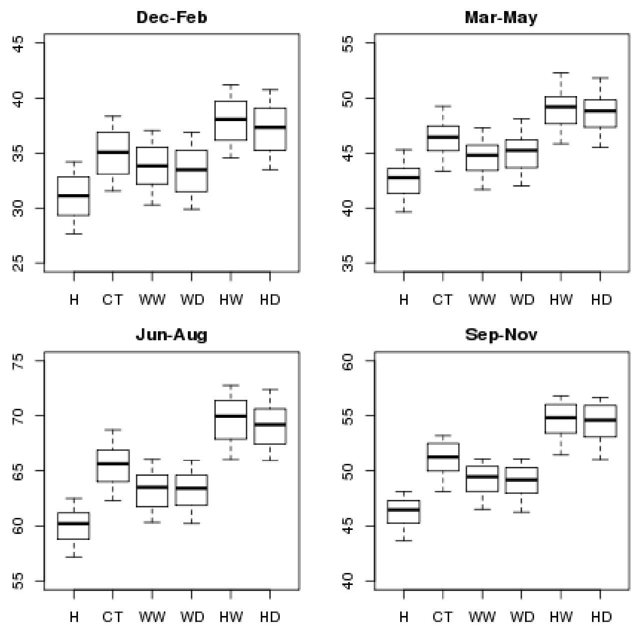


Notes:
1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

Figure 3-29. Seasonal basin mean precipitation (in inches), CMIP5 2070s and historical (1950–1999)

Projections of seasonal temperatures for the 2070s, compared with the historical period (1950–1999) show similar patterns in HDe climate change scenarios across

seasons (refer to Figure 3-30). The hotter HDe scenarios (HW and HD) indicate warmer temperatures relative to the warmer HDe scenarios (WW and WD), compared with historical temperatures. Central tendency scenarios tend to fall in between the warmer and hotter scenarios. What is notable about the seasonal temperature projections is that, for all seasons, the hotter HDe scenarios are mostly outside the range of corresponding historical seasonal temperatures. In summer and fall, even the central tendency HDe scenarios are mostly outside the range of historical temperatures.



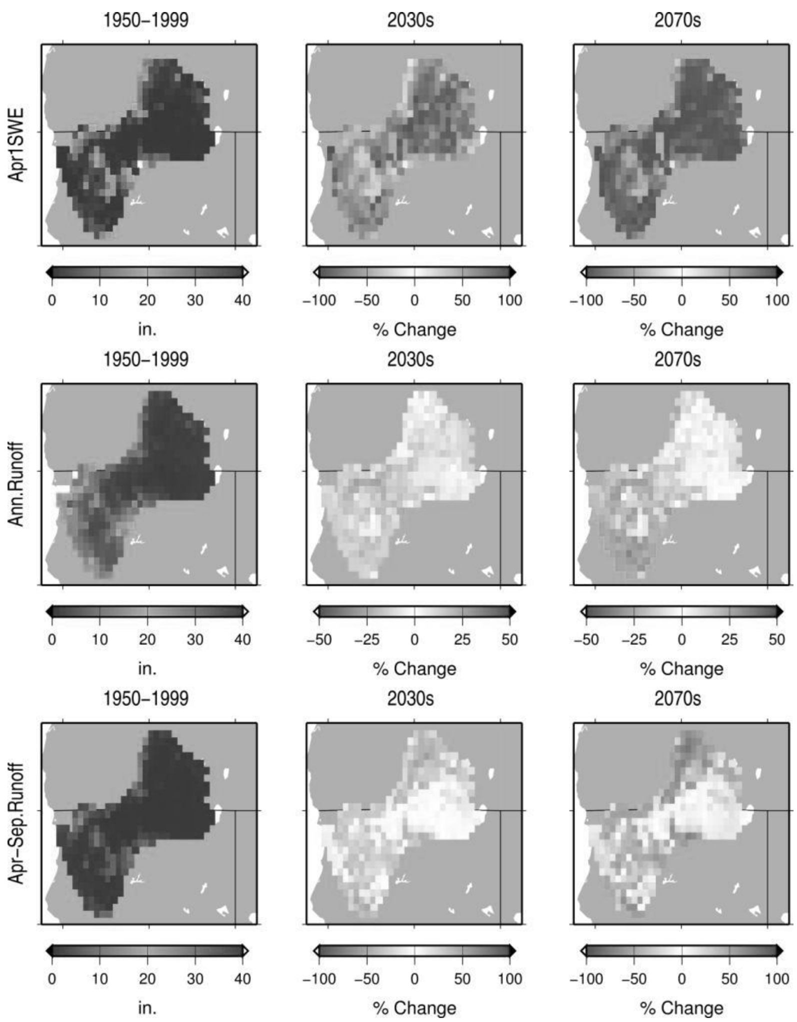
Notes:

1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

Figure 3-30. Seasonal basin mean daily average temperature (in degrees F), CMIP5 2070s and historical (1950–1999)

3.7.1 Changes in Water Balance Terms

This section summarizes projected spatial and basin mean changes in snowpack, annual and spring runoff, soil moisture, and actual ET for the two future time horizons (2030s and 2070s), based on central tendency CMIP5 projections. Figures corresponding to those shown in this section based on CMIP3 projections are included in Appendix B, Supplemental Information for Assessment of Water Supply. It should be noted that paleo-conditioned streamflow projections were not incorporated into the analysis of climate change impacts on surface water balance variables. Figures 3-31 and 3-32 are similar in format in that the left column illustrates mean historical conditions over the period 1950–1999. The middle column illustrates projected percent change for the 2030s future time horizon compared with historical, while the right column illustrates projected percent change for the 2070s future time horizon compared with historical.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from historical values to the 2030s and 2070s, respectively.

Figure 3-31. Comparison of percent change in mean April 1 SWE, mean annual runoff, and mean April-September runoff for the central tendency HDe scenarios based on CMIP5

Mean historical SWE on April 1 (Figure 3-31, top row) falls within the range of little or no snow in the coastal region to almost 40 inches of SWE in the Cascade

Mountains (and even greater snowpack at Mount Shasta). Based on CMIP5 projections, mean percent change in April 1 SWE across the Klamath River Basin is -40 percent for the 2030s and -62percent for the 2070s. Greater decreases are projected for middle to lower elevation parts of the basin. Snowpack at Mount Shasta is expected to exhibit little change (on a percent basis) by the 2030s or 2070s.

Historical mean annual runoff over the 1950–1999 period ranges from a little less than 1 inch in the northeastern part of the basin to more than 40 inches in parts of the coastal region and near Mount Shasta. Basin-wide mean percent change in annual runoff is +12 percent for the 2030s and +15 percent for the 2070s. Most of the Lower Klamath Basin is projected to experience increases in mean annual runoff, while the Cascades region is projected to experience decreases. What is notable with respect to projected changes in mean annual runoff in the Upper Klamath Basin is that projected increases in runoff appear greater for the 2030s than the 2070s. This is likely due to the combined effects of projected increases in precipitation along with projected increases in temperature. For the 2030s, increased precipitation dominates the water balance, resulting in larger increases in annual runoff, while for the 2070s corresponding increases in temperature may cause actual ET to be great enough to show an overall smaller increase in mean annual runoff than for the 2030s.

Future Availability – Water Balance

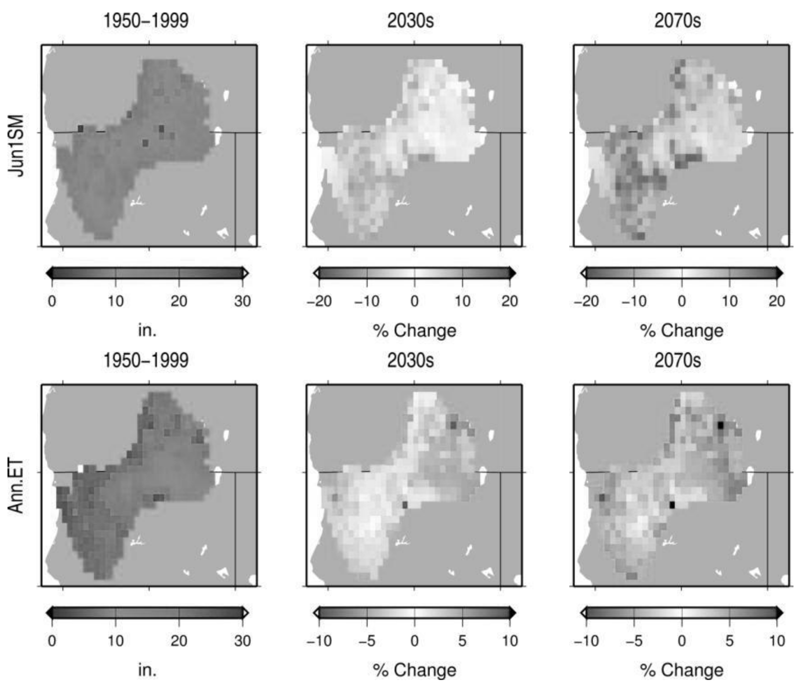
Mean percent change based on CMIP5 central tendency projections includes:

- April 1 SWE: -40 percent (2030s) and -62 percent (2070s)
- Spring (April–September) runoff: -25 percent (2030s) and -40 percent (2070s)
- June 1 soil moisture: -4.9 percent (2030s) and -8.7 percent (2070s)
- Annual ET: +2.6 percent (2030s) and +4.1 percent (2070s)

Historical irrigation season (April through September) runoff over the 1950–1999 period ranges from less than 1 inch to about 30 inches, with higher spring runoff occurring in the mountainous parts of the Klamath River Basin. Mean percent change in spring (April through September) runoff is -25 percent for the 2030s and -40 percent for the 2070s.

Similar to evaluating snowpack at its general peak, projections of soil moisture on June 1 are presented because, in the absence of irrigation or other water management, June is the month of greatest soil moisture throughout the Klamath River Basin. Changes in maximum soil moisture may be of interest to water managers in terms of understanding projected changes in groundwater and soil water availability. Mean historical soil moisture on June 1 over the period 1950–

1999 ranges from less than 1 inch to almost 30 inches, with the greatest soil moisture occurring in mountainous regions with melting snowpack and generally higher precipitation (Figure 3-32). Mean percent change in June 1 soil moisture across the Klamath River Basin is a reduction by 4.9 percent for the 2030s and a reduction by 8.7 percent for the 2070s, compared with the historical period. The pattern of projected change in June 1 soil moisture is similar to that of spring runoff, indicating that projected reductions in soil moisture correspond with reductions in spring runoff. Interestingly, these reductions also correspond with projected increases in mean annual runoff, indicating that there may be a seasonal shift in runoff (discussed in the next section), and therefore June 1 soil moisture.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from 1990s values to the 2030s and 2070s, respectively.

Figure 3-32. Comparison of percent change in mean June 1 soil moisture and mean annual evapotranspiration for the central tendency climate scenario, using groupings of GCMs from CMIP5

Mean historical annual ET over the period 1950–1999 ranges from less than 10 inches to about 33 inches (Figure 3-32). Higher ET values tend to occur in regions with greater water availability (i.e., greater precipitation), like in the Lower Klamath Basin and other mountainous regions. Mean percent change in annual ET basin wide is +2.6 percent for the 2030s and +4.1 percent for the

2070s. Larger percentage increases in ET appear to be projected for parts of the Upper Klamath Basin. However, these results may not reflect relative increases in the amount of water lost to ET, due to the fact that the Upper Klamath Basin generally has lower annual ET.

Figure B-12 in Appendix B, Supplemental Information for Assessment of Water Supply, illustrates projected changes in June 1 soil moisture and mean annual ET for the 2030s and 2070s central tendency, based on the CMIP3 HDe scenarios. Results are similar in spatial patterns of projected change; however, CMIP3-based projections generally indicate smaller projected changes in June 1 soil moisture and annual ET than CMIP5.

3.7.2 Changes in Timing and Quantity of Runoff

This section evaluates projected changes in mean monthly streamflow at selected locations within the Klamath River Basin, the projected shift in timing of mean monthly hydrographs for one example location within the basin, and low flow frequency statistics for select locations. Analyses focus on projected changes for the two future time horizons (2030s and 2070s) based on CMIP5 projections. Figures similar to those presented in this section, but based on CMIP3 projections, are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, the presentation of projected streamflow results at Keno, Oregon (Figure 3-33) includes projections based on both CMIP3 and CMIP5 to allow for direct comparison of mean monthly hydrographs under various types of projections.

Simulated historical and projected mean monthly hydrographs for the Klamath River at Keno, Oregon are presented in Figure 3-33 to illustrate an example of projected changes in overall flow volume and seasonal peak timing of streamflow in the watershed. The top two panels summarize projections based on CMIP3 projections, while the bottom two panels summarize projections based on CMIP5 projections. The mean monthly historical hydrograph is identical in each panel and was computed over water years 1950–1999 (i.e., September 1949–October 1999).

Both CMIP3- and CMIP5-based projections indicate a decrease in spring and summer streamflow for the 2030s and a greater decrease by the 2070s. The wetter of the five HDe climate change scenarios (HW and WW) indicate greater streamflow volume overall, along with higher seasonal peaks. Drier scenarios (HD and WD) indicate reduced streamflow volumes and reduced peaks. Projections for the 2030s (based both on CMIP3 and CMIP5) indicate a shift in seasonal peak timing from approximately zero to one month earlier (a shift from April to March). For the 2070s, projected shifts in seasonal peak timing are zero to two months earlier (a shift from April to as early as February).

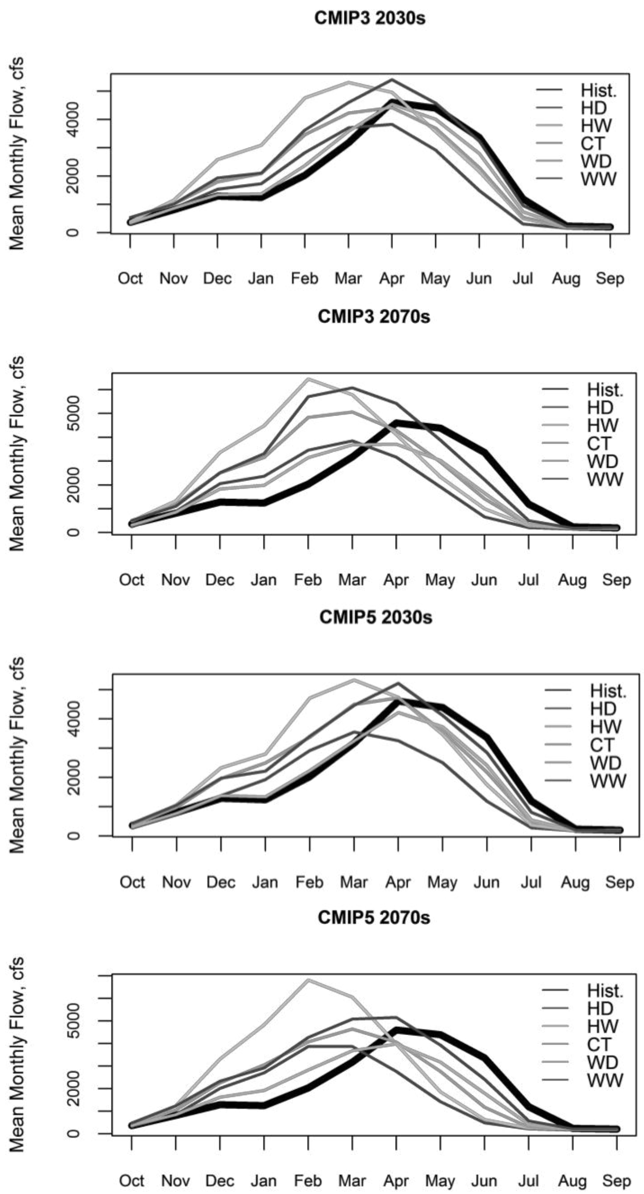


Figure 3-33. Historical and projected mean monthly hydrographs for Klamath River at Keno, OR (USGS ID 11509500)

The projected shifts in streamflow volume and timing for Keno, Oregon are typical of those sub-basins within the Klamath River Basin that are influenced in part by snowmelt. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume. Wetter scenarios indicate greater increases, while drier scenarios indicate anywhere from a slight decrease in flow volume to a slight increase in flow volume (figures not shown).

The seasonality of streamflow, in particular low flow periods, is of interest to water managers since there is often limited supply for numerous competing resources during low flow periods. At the same time, natural streamflow variability, including low flows, serves an important function for a river ecosystem. Richter et al. (1997) discuss an approach for setting streamflow-based targets for ecosystem management. The approach is based on the notion that streamflow characteristics are useful indicators for assessing ecosystem integrity over time. One of the identified indicators is the annual 7 day minimum of flow. As part of the assessment of future water supply, we evaluated projected changes in the 7Q10 low flow frequency statistic. This statistic is defined as the lowest 7 day mean flow at a location, occurring at a 10 year recurrence interval. As one example of its application, this statistic is used to define the “critical condition” for adverse impact on aquatic biota in Washington state (Chapter 173-201A of the Washington Administrative Code). As part of this assessment, the 7Q10 low flow frequency statistic is evaluated for a number of sites throughout the Klamath River Basin.

Projected changes in the 7Q10 low flow frequency statistic were evaluated as part of the Klamath River Basin water supply assessment as a way of focusing on changes in streamflow during their seasonal low periods. Low flow periods typically occur in late summer when precipitation is low, stored water supplies have largely been consumed, and anadromous fish species begin their upstream migration to spawning grounds.

Table 3-7 summarizes projected changes in 7Q10 low flow frequency for eight selected sites throughout the Klamath River Basin. Primary projected values in the table represent the central tendency, while the values in parenthesis represent the range of the five HDe climate change scenarios for CMIP3 and CMIP5 for each future time horizon. Projected changes were computed as a ratio between the projected value and the historical value. Values greater than one indicate an increase in the 7Q10 low flow, while values less than one indicate a decrease in the 7Q10 low flow (these are shown in bold in the table).

Table 3-7. Summary of ratios between projected and historical 7Q10 low flow frequency statistics for various sites within the Klamath River Basin

Site ID	Site Name	Hist. 7Q10 (cfs)	2030s CMIP3	2030s CMIP5	2070s CMIP3	2070s CMIP5
00020	Sprague R near Chiloquin	68.6	1.03 (**0.943**-1.06)	1.00 (**0.955**-1.05)	1.01 (**0.917**-1.07)	1.01 (**0.927**-1.07)
00026	Klamath R blw Iron Gate Dam	167	**0.989** (**0.965**-1.01)	**0.989** (**0.970**-1.01)	**0.994** (**0.949**-1.01)	**0.995** (**0.952**-1.01)
00004	Klamath R at Orleans	313	**0.998** (**0.980**-1.01)	**0.995** (**0.982**-1.01)	**0.996** (**0.969**-1.01)	**0.994** (**0.977**-1.01)
00029	Klamath R near Klamath	443	1.00 (**0.983**-1.00)	**0.997** (**0.989**-1.00)	**0.998** (**0.977**-1.00)	**0.996** (**0.981**-1.00)
00022	Salmon R at Somes Bar	23.4	**0.966** (**0.932**-1.01)	**0.979** (**0.957-0.966**)	**0.949** (**0.940-0.996**)	**0.983** (**0.953-0.987**)
00031	Shasta R near Yreka	29.2	1.01 (**0.990**-1.01)	1.01 (**0.979**-1.01)	1.02 (**0.990**-1.02)	1.02 (**0.979**-1.02)
00032	Scott R near Ft Jones	25.9	1.02 (1.01-1.04)	1.04 (1.01-1.05)	**0.996** (**0.996**-1.03)	1.07 (**0.981**-1.07)
00034	Trinity R at Hoopa	99.4	1.01 (1.00-1.01)	1.01 (1.00-1.02)	1.02 (1.00-1.02)	1.01 (1.01-1.02)

Note: Primary values represent the central tendency HDe scenario. Values in parenthesis represent the range of the five HDe climate change scenarios. Values above 1 indicate an increase. Values less than 1 indicate a decrease (shown in bold).

Select sites on the Sprague, Shasta, Scott, and Trinity Rivers are projected to experience increases in 7Q10 low flows for the 2030s and 2070s central tendency, compared with the historical period; however, projections range from slight decreases to slight increases. Projected increases are largely due to projected increases in precipitation. The Trinity River site (00034) is the only site evaluated where the entire range of projections indicate an increase in the 7Q10 low flow statistic. Select sites including three on the mainstem Klamath River (below Iron Gate Dam, at Orleans, and near Klamath) and one on the Salmon River are projected to experience decreases in the 7Q10 low flow central tendency, compared with the historical baseline; however, projections range from slight decreases to slight increases. The Salmon River site (00022) is the only one evaluated where the entire range (except for the 2030s CMIP3) indicates a decrease in the 7Q10 low flow statistic. Projected decreases are likely due to the combined effects of increased precipitation, increased temperature,

Future Availability – Runoff Quantity and Timing

For those basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

and increased ET. It should be noted that projections based on CMIP3 and CMIP5 show similar results in their central tendency.

Projections shown in Table 3-7 are based on streamflow generated by the VIC hydrologic model which represents natural flow, absent of management effects such as withdrawals and groundwater pumping. Combined effects of changes due to climate change and changes in management practices may alleviate or exacerbate projected changes in low flows in the Klamath River Basin. It should be stressed that the historical values presented in Table 3-7 are lower than those typically experienced in the watershed. These values are based on the lowest 7-day running mean that has a 1:10 chance of occurrence. Such an occurrence would likely occur in a prolonged drought condition where groundwater levels (which would typically provide supplemental baseflow) are also negatively impacted. In addition, it should be noted that the VIC model does not represent complex surface and groundwater interactions and therefore may not generate realistic baseflow in a heavily groundwater influenced watershed such as the Klamath River Basin. Additional discussion related to VIC model limitations is provided in Appendix B, Supplemental Information for Assessment of Water Supply.

3.7.3 Changes in Drought and Surplus based on Paleo Conditioned Streamflow Projections

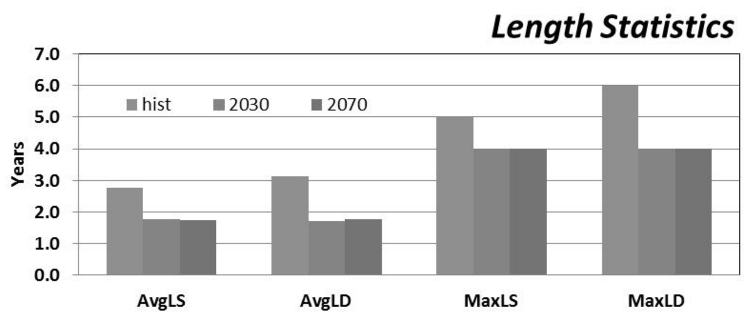
Using the approach described in Section 3.5.1.3, Deriving Paleo-Conditioned Streamflow Projections, drought and surplus statistics were analyzed for all HDe scenarios to characterize projected changes in droughts and surpluses. Drought and surplus statistics may be generated at any streamflow location in the Klamath River Basin using this approach. For the Klamath River Basin water supply assessment, we focus on results at the Klamath River near Klamath, California, which represents the integrated response to drought and surplus throughout the basin since it is close to the mouth of the river. Results are summarized graphically for the 2030s and 2070s for CMIP5-based central tendency scenarios in Figure 3-34. The data behind the figure, in addition to other HDe climate change scenarios, is summarized by Tables B-1 and B-2 in Appendix B, Supplemental Information for Assessment of Water Supply.

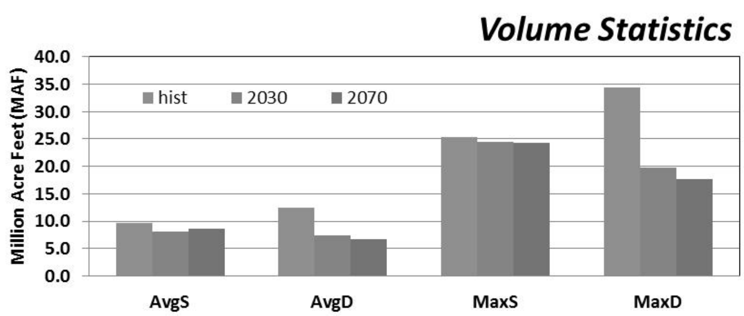
Future Availability – Droughts and Wet Periods

Analyses of surplus and drought statistics based on the paleo record are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes.

Overall, the surplus and drought statistics are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes. The projections correspond

with projections of increased precipitation overall in the Klamath River Basin for both future time horizons (2030s and 2070s). In spite of these statistics pointing to wetter conditions, the maximum surplus volumes are estimated to be nearly equal to the historical maximum surplus. The paleo-hydrologic analysis provides a way to superimpose variability by altering sequences, and for water systems the sequence in which wet and dry spells occur is critical.





Note: AvgLS and AvgLD: average length of surplus and drought, respectively. MaxLS and MaxLD: maximum length of surplus and drought, respectively. AvgS and AvgD: average surplus and drought, respectively MaxS and MaxD: maximum length of surplus and drought, respectively.

Figure 3-34. Surplus and drought statistics for the paleo-conditioned CMIP-5 central tendency climate scenario

3.7.4 Changes in Groundwater Supply

The impacts of climate change on groundwater supplies were evaluated for three primary groundwater basins within the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys. Similar to the assessment of surface water supplies, this assessment focuses on results based on CMIP5 projections. Figures similar to those presented below but based on

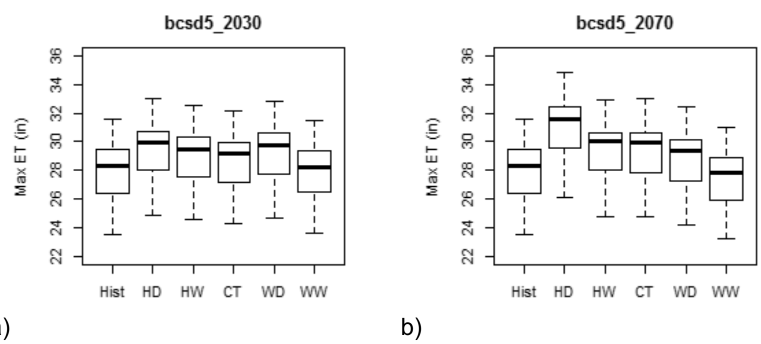
CMIP3 projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. This assessment also focuses on groundwater impacts as a result of projected changes in climate and surface water hydrology (as well as population for the Scott and Shasta Valleys) and does not consider changes in pumping or other changes in water management.

3.7.4.1 Upper Klamath Basin

The following analysis of climate change impacts focuses first on the perturbed inputs of maximum ET and mean annual recharge for the projected MODFLOW simulations, and then on MODFLOW simulation results including projected changes in groundwater elevations and discharge to surface water.

Inputs

Projections for the three perturbed MODFLOW input terms are first discussed to provide context for the discussion of projected changes in groundwater elevations and discharge. Figure 3-35 shows historical and projected mean maximum ET (as defined in the approach) for the five HDe climate change scenarios on an annual basis. As described in the approach, projected maximum ET values were computed based on annual change factors applied to historical maximum ET. The figure shows that mean annual maximum ET is projected to increase for the 2030s and 2070s, compared with the historical period, when looking at corresponding percentile levels. For the 2030s, the drier scenarios (HD and WD) appear to have slightly larger increases than the wetter scenarios. For the 2070s, the HD scenario indicates a larger increase in maximum ET than all other scenarios.



Notes:
1. The heavy black line represents median of values across the 47 VIC cells within the Upper Klamath Basin MODFLOW model domain that contains evapotranspiration cells (defined by Gannett et al. [2012] Figure 4), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

Figure 3-35. Summary of projected mean annual maximum ET for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years

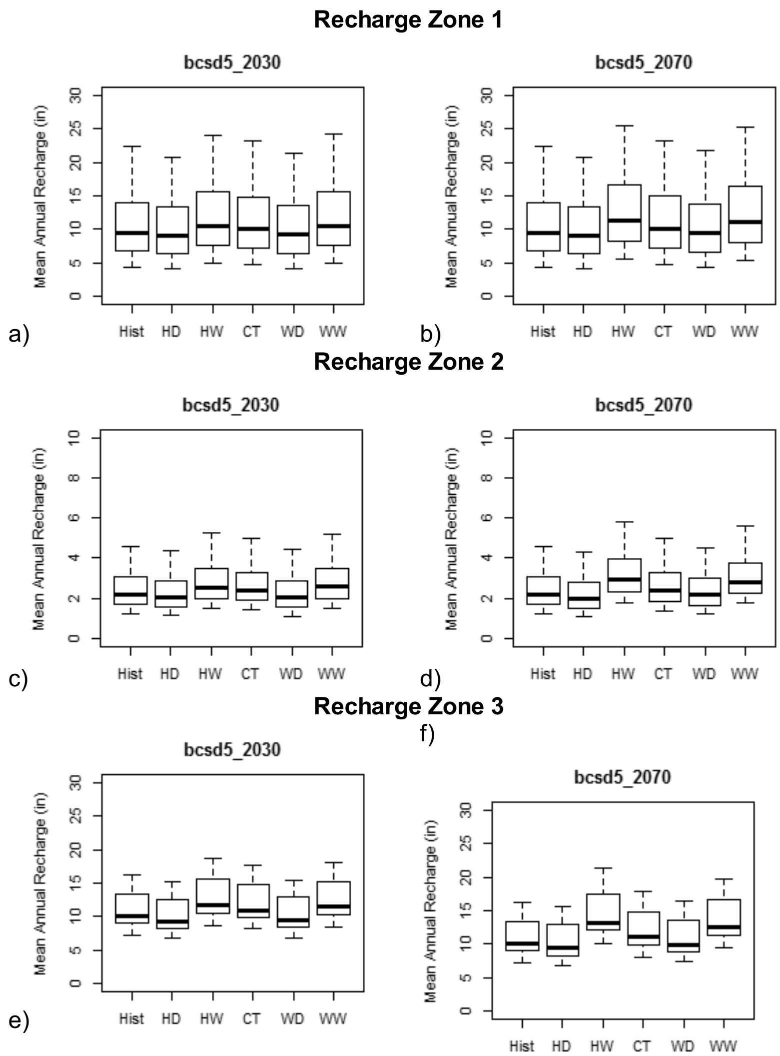
Table 3-8 summarizes the projected increases in the central tendency of mean annual maximum ET for the 2030s and 2070s, for projections based both on CMIP3 and CMIP5. Results show greater increases in maximum ET for projections based on CMIP3 than those based on CMIP5.

Table 3-8. Summary of central tendency projections of maximum ET for the 2030s and 2070s, compared with the historical baseline (1970–1999).

Central Tendency Projections	2030s	2070s
CMIP3	+4.5%	+7.1%
CMIP5	+3.3%	+5.7%

Projected recharge was input into future simulations of the Upper Klamath Basin MODFLOW model for five HDe climate change scenarios (for two future time periods and both CMIP3 and CMIP5), based on unique historical precipitation-recharge relationships by recharge zone. Figure 3-36 illustrates box plots of projected mean annual recharge by zone based on CMIP5 projections (refer to Figure 3-10 for identification of recharge zones). In general, projections of recharge are similar between future time horizons, both in magnitude and when considering the relative change across different climate change scenarios. Recharge zone 1 has a greater range of recharge (as evidenced by the difference between 5th and 95th percentile values) than zones 2 or 3. Also, recharge zone 2 has substantially lower recharge than the other zones, including the historical values. Lower recharge in zone 2 likely corresponds with less precipitation and snowpack to help drive recharge. Projected changes in mean annual recharge for zone 1 range from increases to small decreases. Wetter scenarios generally indicate increases in recharge, while drier scenarios generally indicate decreases, particularly looking at the median (50^{th} percentile) change.

Table 3-8 summarizes mean annual recharge by zone, and basin-wide, for the central tendency (2030s and 2070s, CMIP3 and CMIP5). For the 2030s, projected changes in recharge differ substantially between CMIP3- and CMIP5-based scenarios. However, by the 2070s CMIP3- and CMIP5-based scenarios are more similar. In fact, the difference in projected recharge change for zone 1 is almost as great between CMIP3 and CMIP5 for the 2030s as the difference between the 2030s and 2070s based on CMIP3. These results were verified; however, it illustrates how closely recharge projections correspond with projections of future precipitation. Basin-wide precipitation changes for the central tendency are projected to be about +2.4 percent (based on CMIP3) and +4.1 percent (based on CMIP5) for the 2030s and about +5.2 percent (based on CMIP3) and +6.1 percent (based on CMIP5) for the 2070s. Projections of recharge for other HDe climate change scenarios show similar correspondence with precipitation projections.



Notes:

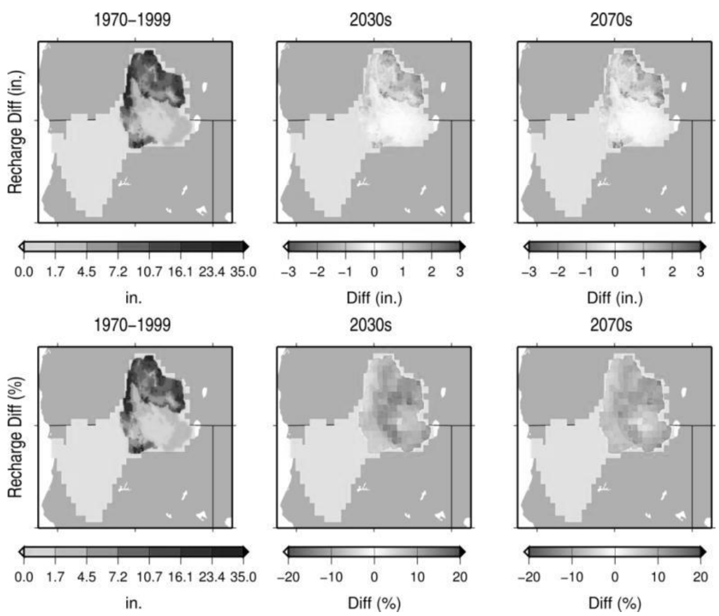
1. Heavy black line represents median of values across the 62 VIC cells within the MODFLOW model domain that are within recharge zone 1, while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

Figure 3-36. Summary of projected mean annual recharge for MODFLOW model recharge zone 1 for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years

Table 3-9. Summary of central tendency projected change in mean annual recharge by zone for the 2030s and 2070s, compared with the historical baseline (1970–1999 water years)

Central Tendency Projections	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Recharge Zone 1	+3.0%	+6.1%	+7.9%	+6.5%
Recharge Zone 2	+4.3%	+8.9%	+8.0%	+9.4%
Recharge Zone 3	+4.6%	+8.8%	+10.5%	+10.0%
Basin Wide	+3.4%	+8.4%	+8.8%	+8.2%

Figure 3-37 spatially illustrates historical and projected change in mean recharge for CMIP5-based central tendency scenarios (2030s and 2070s) based on data used as input by the MODFLOW model for the Upper Klamath Basin. The left column contains identical panels (top row and bottom row) showing the historical seasonal mean recharge (in inches) used in the calibrated model (similar to Figure 3-10). The middle and right columns contain projected change for the 2030s and 2070s, respectively (top row in inches, bottom row in percent change).



Note: The left-hand column illustrates the historical values (top row and bottom row are identical), while the middle and right-hand columns illustrate change (top row in inches, bottom row in percent change) from 1970-1999 values to the 2030s and 2070s, respectively.

Figure 3-37. Comparison of change in mean annual recharge to groundwater for the central tendency climate scenarios, using groupings of GCMs from CMIP5

Outputs

The Upper Klamath Basin MODFLOW model was implemented using projected inputs as previously described. For the purpose of the Klamath River Basin water supply assessment, historical pumping was used to explore the effects of climate change alone on the groundwater balance.

The MODFLOW model computes an overall groundwater budget on a seasonal timestep. Table 3-10 summarizes projected mean changes in the primary output components of the budget for the central tendency HDe scenario. These components consist of groundwater discharge to drains, evapotranspiration, and groundwater discharge to streams. Drains include surface water conveyances such as constructed canals and ditches and natural springs. Units for discharge to drains may be described as cubic feet per second (cfs) per grid cell, where discharge (in cfs) is the mean computed over the simulation period (water years 1970–1999) and across all MODFLOW grid cells designated as drains. Basin-wide changes in groundwater discharge to drains are projected to increase by less than two percent for both the 2030s and 2070s. Considering four central tendency scenarios (CMIP3 2030s and 2070s as well as CMIP5 2030s and 2070s), the greatest increase in discharge to drains is projected for the CMIP5-based 2030s scenario. The integration of projected changes in temperature and precipitation in the modeled domain (i.e., the Upper Klamath Basin) indicate greater increases for the 2030s than for the 2070s based on CMIP5.

Units for ET are inches, where ET is the mean computed over the simulation period and across all MODFLOW grid cells designated as having ET. Projected changes in mean ET indicate increases according to all central tendency projections (Table 3-10), with greater increases projected for the 2070s than for the 2030s. ET corresponds more closely with temperature than with precipitation. Projections of annual temperature (Table 3-5) indicate similar projected increases in the central tendency for the 2030s (CMIP3 and CMIP5) and similar yet greater increases for the 2070s.

Discharge to streams is presented in units similar to discharge to drains, namely mean discharge (cfs) per MODFLOW grid cell designated as stream. Seasonal mean discharge to streams is projected to increase, with the greatest increases projected for the CMIP5 2030s and the CMIP3 2070s scenarios (Table 3-10).

Table 3-10. Average percent change in mean groundwater balance variables

Central Tendency Projections	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
GW Losses to Drains	+0.4%	+1.8%	+1.2%	+1.3%
GW Losses to ET	+4.1%	+5.2%	+7.3%	+6.4%
GW Losses to Streams	+2.0%	+5.2%	+5.3%	+4.8%

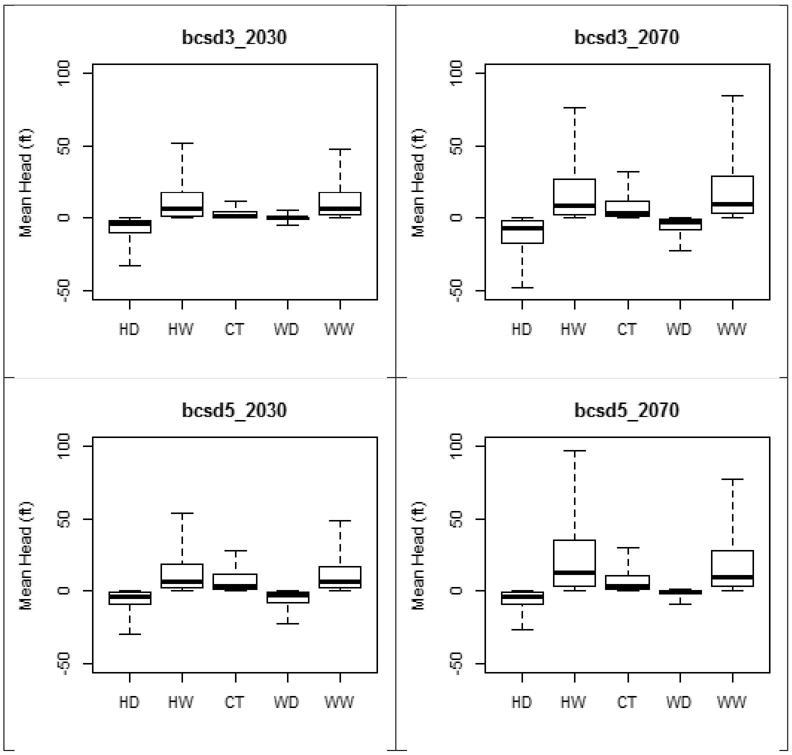
In addition to projected changes in the overall groundwater budget, projected changes in groundwater head for the three vertical layers represented in the MODFLOW model were evaluated as part of the water supply assessment. Groundwater head corresponds with the elevation of the water table. Projected changes in mean groundwater head for the central tendency scenario (2030s CMIP3 and CMIP5 as well as 2070s CMIP3 and CMIP5) are summarized in Table 3-11. Groundwater head is projected to increase by between 1.8 and 7.8 feet for the 2030s (central tendency) and between 4.4 and 8.2 feet for the 2070s.

Table 3-11. Average change in groundwater head due to MODFLOW simulations based on projected changes in all variables for the central tendency projection

Central Tendency Projected Change (in feet)	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Change in Head, All, Layer 1	3.1	7.8	8.2	7.7
Change in Head, All, Layer 2	2.0	5.0	4.9	4.8
Change in Head, All, Layer 3	1.8	4.6	4.4	4.3

Note: "All" variables include recharge and max ET

Figure 3-38 focuses on layer 1 and shows how projected changes in groundwater head (in feet) for the central tendency compare with other HDe scenarios. Layer 1 is presented because it has the greatest sensitivity to projected climate changes. The wetter scenarios (HW and WW) generally indicate larger increases in groundwater head than the central tendency, while the drier scenarios (HD and WD) indicate smaller increases or even decreases in groundwater head, depending on the type of projection (CMIP3 or CMIP5) and time horizon (2030s or 2070s).

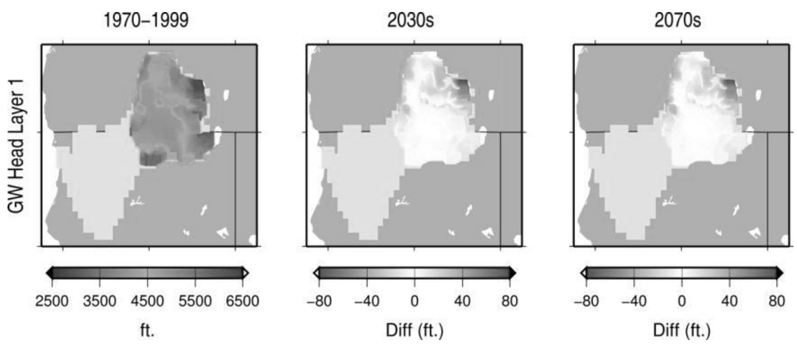


Notes:

1. The heavy black line represents median of values across the roughly 32,000 cells within the MODFLOW model domain (MODFLOW spatial resolution), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW=– hot wet, HD = hot dry.

Figure 3-38. Summary of difference in projected mean groundwater head for MODFLOW model layer 1 for 2030s and 2070s time horizons compared with the historical baseline period of 1970–1999 water years

Projected changes in groundwater head for layer 1 for the CMIP5-based central tendency scenario are presented spatially in Figure 3-39. The left column illustrates historical mean seasonal groundwater head over the simulation period 1970–1999 (water years), while the middle and right columns illustrate projected changes in feet for the 2030s and 2070s, respectively. The figure shows that projected changes may result in a substantial depth of water, up to about 50 feet in the northeast portion of the basin. As a point of reference, land surface elevations in the Upper Klamath Basin modeled domain range from 2,500 feet to 8,500 feet.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate change (in feet) from 1970–1999 values to the 2030s and 2070s, respectively.

Figure 3-39. Comparison of change in mean groundwater head in the uppermost layer of the MODFLOW model for the central tendency climate scenario, using groupings of GCMs from CMIP5

The following analysis summarizes projected discharge to individual stream reaches across the Upper Klamath Basin, as defined in Figure 3-40. Projections summarized in Table 3-12 indicate increases in groundwater discharge for all designated stream reaches. Similar to projections of precipitation and recharge, CMIP5 projections for the 2030s show larger increases than CMIP3 projections, while for the 2070s CMIP3 projections show larger increases than CMIP5. Also, CMIP3 2030s projections show the greatest change overall (even greater than for the 2070s). As previously discussed, the relative differences between scenarios are a result of the process of grouping GCM projections as part of the HDe approach. The smallest projected increases are for Lost River and Wood River reaches, while the largest projected increases are for Sycan and Sprague River reaches.

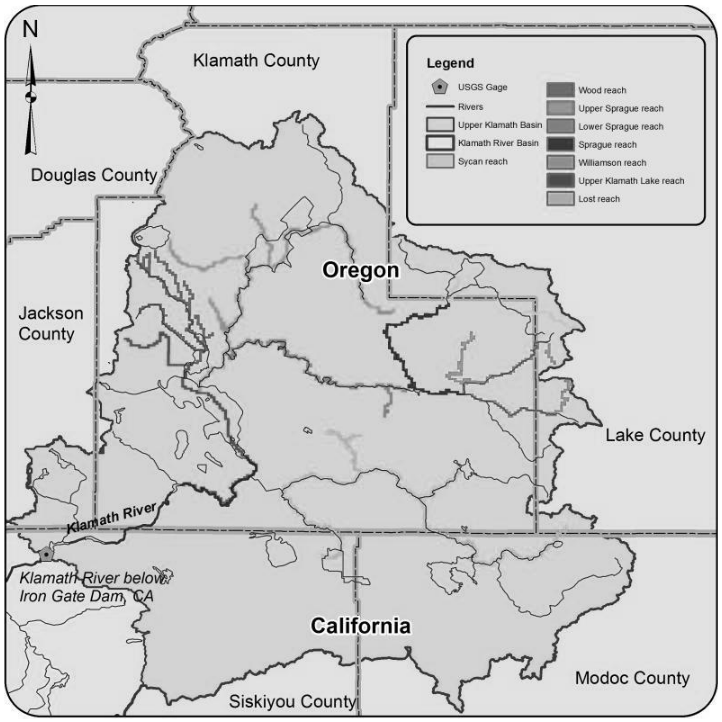


Figure 3-40. Overview map of MODFLOW stream reaches analyzed as part of the Klamath River Basin Study water supply assessment

Table 3-12. Average percent change in groundwater losses to streams over the simulation period for central tendency projections

Central Tendency Projections (Percent Change)	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Lost River	+0.7%	+2.6%	+1.9%	+1.7%
Lower Sprague	+2.8%	+6.5%	+6.8%	+5.3%
Sprague	+3.5%	+9.1%	+8.7%	+8.0%
Sycan	+5.2%	+13%	+13%	+12%
Upper Klamath Lake	+1.2%	+3.5%	+4.0%	+3.6%
Upper Sprague	+2.6%	+7.4%	+6.8%	+6.7%
Williamson	+2.7%	+6.9%	+7.6%	+6.2%
Wood River	+1.0%	+3.0%	+3.6%	+3.1%

3.7.4.2 Scott Valley

The groundwater screening tools developed for the Scott and Shasta Valleys allow for the evaluation of projected changes in mean groundwater elevation. Figure 3-41 illustrates projected changes in monthly groundwater elevations for the two future time periods based on CMIP5 (panels a and b). Individual boxes in each panel represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. The historical simulation period is calendar years 1980–1999, while the future simulation period is effectively a 50-year period that represents the characteristics of the chosen future time horizon (2030s or 2070s, in this case). Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period in the absence of any changes in groundwater use beyond that associated with population growth. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases.

a) b)

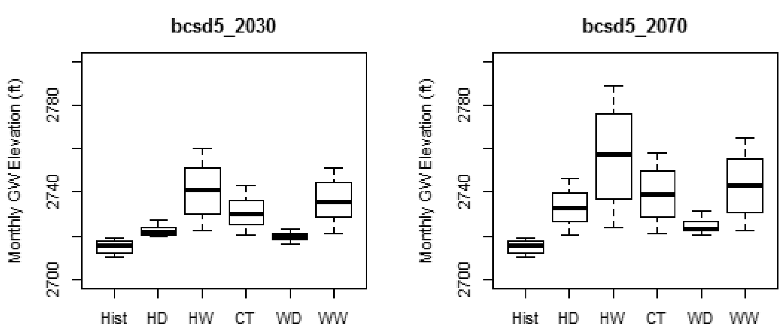


Figure 3-41. Summary of projected groundwater elevation for Scott Valley

The central tendency projections fall in between, with a median projection of a 15 foot increase in groundwater elevation by the 2030s and a 23 foot increase by the 2070s. To provide some context, the Scott and Shasta Valleys experienced fluctuations in annual groundwater elevation of about 20 feet over the period 1980–1999. Projected increases in groundwater elevation in the Scott Valley correspond with projected increases in precipitation in the watershed. Projected increases in actual ET computed by the VIC surface water hydrologic model (based on an assumption of natural vegetation) are not great enough to offset the projected increases in precipitation, resulting in greater potential for groundwater recharge.

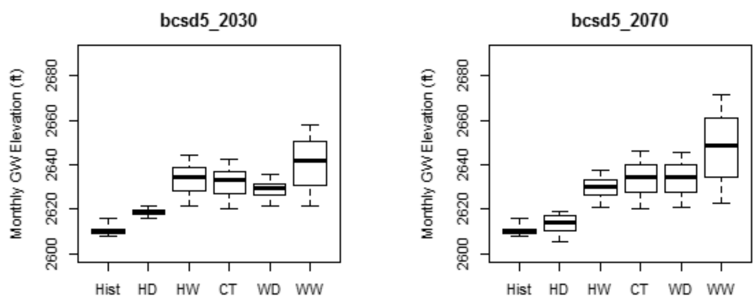
It is notable that the HW scenario based on CMIP5 indicates a greater increase in groundwater elevation than the cooler (WW) scenario. One would expect the HW scenario to have a smaller increase in groundwater elevation due to greater ET losses. However, the HW scenario may actually be wetter than the WW scenario, which may compensate for any additional ET losses due to higher temperatures.

CMIP3- and CMIP5-based projections are similar for the two future time horizons; however CMIP5-based projections generally result in greater increases in groundwater elevation, corresponding with greater increases in precipitation compared with CMIP3. Individual scenarios may also differ to due to the automated selection process for individual GCM projections within a quadrant (refer to Section 3.5.1.1, Climate Projections for additional explanation of the projection selection procedure).

3.7.4.3 Shasta Valley

Projected changes in monthly groundwater elevation for the Shasta Valley are summarized in Figure 3-42 (panels a and b) for the two future time periods based on CMIP5. Box plots are similar to those in Figures 3-41 and represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations in the Shasta Valley.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. The central tendency scenarios based on CMIP5 indicate about a 24-foot increase in groundwater elevation for the 2030s and a 25-foot increase for the 2070s, compared with the historical baseline. To provide context, historical Shasta Valley groundwater elevations fluctuated approximately 20 feet over the historical simulation period. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases. The WW scenario indicates the greatest projected change, likely because ET rates are probably lower than in the hotter scenarios and more water may be available for groundwater recharge.



a) b)

Figure 3-42. Summary of projected groundwater elevation for Shasta Valley

A majority of the projections for the 2070s show greater increases in groundwater elevation than for the 2030s, with the exception of the hotter scenarios (for example, CMIP3-based HD and CMIP5-based HD and HW). A smaller increase in groundwater elevation in the 2070s compared with the 2030s, despite greater projected increases in precipitation, may be due to the combined effects of increased ET corresponding with higher temperatures.

When comparing CMIP3-based projections with CMIP5-based projections, the differences in median projections of monthly groundwater elevation are more dissimilar than would be expected. For example, the median monthly change in groundwater for the 2070s compared with the historical baseline is almost 5 feet for CMIP5 and 12 feet (more than double) for CMIP3. This example illustrates the importance of considering a wide range of climate scenarios (including both CMIP3 and CMIP5) in the analysis of water supply impacts.

Future Availability – Scott and Shasta Valley Groundwater

Projected monthly groundwater elevations in the Scott and Shasta Valley alluvial aquifers (as defined by CDWR Bulletin 118) for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. However, the projected changes are within or close to the historical fluctuations in groundwater elevation in the two basins (on the order of 20 feet for both basins).

3.8 External Factors Affecting Water Supply

In addition to detailed analysis of historical and projected surface and groundwater supplies, this chapter also discusses existing knowledge and research regarding historical and projected sea level rise and wildfire risk. We acknowledge that these phenomena have and may continue to change due to projected changes in climate, and they are important considerations when analyzing water supplies in the Klamath River Basin. Sea level rise poses many risks to the coastal landscape and population. Projected increase in wildfires also poses risks to water supply through increased sediment loads to lakes, reservoirs, and streams, potential damage to water supply infrastructure, and changes to landscape characteristics that affect water temperatures, infiltration dynamics, and runoff timing, among other things.

3.8.1 Projected Sea Level Rise

A warming climate causes global sea level to rise by two primary mechanisms: increasing ocean volume due to expanding sea water associated with warming, and the melting of land ice. Other, more regional phenomena impact the extent of sea level rise off the coast of Oregon and California. For instance, climate patterns such as El Niño and the PDO affect winds and ocean circulation, raising local sea level during warm phases (e.g., El Niño) and lowering sea level during cool phases (e.g., La Niña). Large El Niño events can raise coastal sea levels by 4 to 12 inches for several winter months (NRC, 2012). Tectonics may also affect regional sea levels. In some regions, tectonics may cause the land surface to rise in some regions and fall in others, indicating rising and falling sea levels, respectively. For example, records from 12 west coast tide gages indicate local variability in sea-level change along the coast, although most of the gages north of Cape Mendocino, California, show that relative sea level has been falling over the past 6–10 decades (NRC, 2012). Sea level projections due to climate change are confounded by changes due to naturally occurring phenomena described above.

This section summarizes the findings from three primary documents describing the impacts of climate change on sea level rise in the coastal region of the Klamath River Basin. The first is a 2012 assessment by the National Research Council of best available science with respect to sea level rise in California, Oregon, and Washington. The second document is the Public Draft Report of the most recent National Climate Assessment, which was published in 2013. At the completion of the Klamath River Basin Study water supply assessment, the final National Climate Assessment Report was yet not complete. The third document is the State of California Sea Level Rise Guidance Document, which was published in 2013 by the Coastal and Ocean Working Group of the California Climate Action Team. This document provides guidance for incorporating sea-level rise projections in planning and decision-making for projects in California, but also summarizes existing knowledge on projected sea level rise.

National Research Council (2012) summarized past and projected sea-level rise for the coasts of California, Oregon, and Washington. The assessment states that

vertical land motion from geological processes and human activities, estimated by global positioning system (GPS) measurements, show that much of the western coast north of Cape Mendocino (including the coastal region of the Klamath River Basin) is rising about 0.06–0.1 inches per year (NRC, 2012). Flooding and erosion in coastal areas is already occurring and is damaging some areas of the California coast during storms and extreme high tides (Garfin et al., 2014). Rising land masses may exacerbate the issue of coastal flooding and erosion.

Projections for the Washington, Oregon, and California coasts north of Cape Mendocino indicate that sea level is projected to change between -2 inches (sea-level fall) and +9 inches by 2030, between -1 inch and +19 inches by 2050, and 4–56 inches by 2100 (NRC, 2012). Sea level is likely to rise at a greater rate during the 21st century than it has in the 20th century. Figure 3-43 illustrates projected sea level rise (in centimeters) along the entire west coast of the U. S.

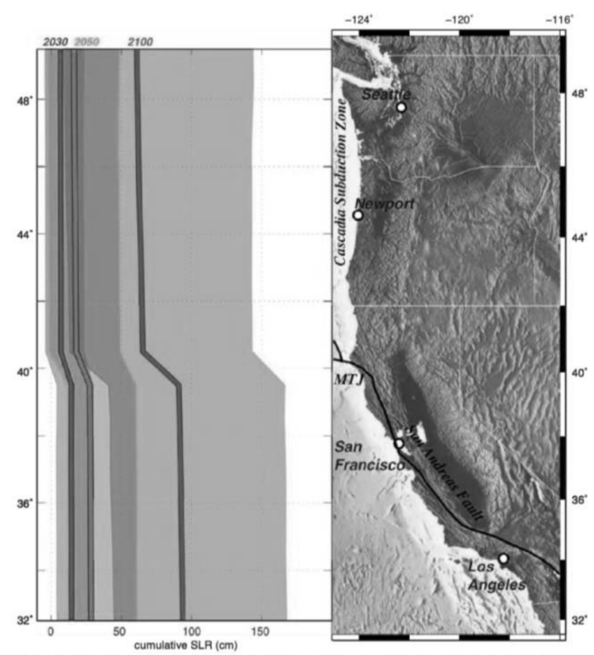


FIGURE S.1 Projected sea-level rise off California, Oregon, and Washington for 2030 (blue), 2050 (green), and 2100 (pink), relative to 2000, as a function of latitude. Solid lines are the projections, and shaded areas are the ranges. Ranges overlap, as indicated by the brown shading (low end of 2100 range and high end of 2050 range) and blue-green shading (low end of 2050 range and high end of 2030 range). MTJ = Mendocino Triple Junction, where the San Andreas Fault meets the Cascadia Subduction Zone.

Source: NRC, 2012, Figure S.1

Figure 3-43. Projected sea level rise along the west coast of the United States

Risks associated with projected sea level rise include the increased risk of coastal flooding, storm surge inundation, coastal erosion and shoreline retreat, and wetland loss. NRC (2012) highlights the significant risk posed to the region north of Cape Mendocino from a large earthquake (magnitude greater than 8) along the Cascadia Subduction Zone, which could cause significant land subsidence resulting in instantaneous sea-level rise as well as a tsunami. In addition, many coastal wetlands, tidal flats, and beaches will likely decline in quality and extent as a result of sea level rise.

3.8.2 Projected Wildfire Risk

The sections of the Public Draft of the most recent National Climate Assessment most relevant to the area of this study (Garfin et al., 2013 for the southwest U.S.; Mote et al., 2014 for the northwest U.S.) summarize past and projected trends in wildfire risk along the west coast, including the greater region surrounding the Klamath River Basin. Increased warming, due to climate change, and drought have increased wildfires and impacts to people and ecosystems in the Southwest, including California. A number of studies have documented increases in wildfire fire season duration and fire frequency and project increases in the probability of large wildfires. Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s (Mote et al., 2013). Between 1970 and 2003, warmer and drier conditions increased the burned area in western U.S. mid-elevation conifer forests by 650 percent (Westerling et al., 2006). Models project up to 74 percent more fires in California in the future (Westerling et al., 2012).

Some of the causes of increased wildfire risk include projected decreases in late summer stream flows in some parts of the Klamath River Basin, changes in the timing and amount of recharge, increases in evapotranspiration, and declines in the groundwater table due in part to increases in pumping demand. Potential increases in water deficits may increase tree stress and mortality, tree vulnerability to insects, and fuel flammability (Mote et al., 2013). Also, an increased risk of watershed vegetation disturbance is anticipated due to increased wildfire potential (Interior and CDFG, 2011).

3.9 Uncertainties Associated with Impacts Assessment Approach

In accordance with common practice, the impacts assessment methodology employed here is based on using a series of models with the outputs of one model serving as the input to the next model. Since there are uncertainties associated with each model step, and the inputs driving each model step are themselves uncertain, this can lead to a “cascade of uncertainty” (IPCC 2007, here), although there may be situations where one model’s tendency to over- or under-estimate may be countered at least to some extent by another’s tendency to err in the other direction. While this study has not developed an estimate of the cumulative

uncertainties in the results based on this methodology, this section summarizes uncertainties associated with various aspects of the Klamath River Basin Study water supply assessment, including the use of climate change scenarios as well as surface and groundwater hydrologic models to evaluate climate change impacts. Additional discussion regarding the use of GCM climate projections and applied downscaling techniques is provided by Reclamation (2011d). The nature of these uncertainties is only briefly described below.

3.9.1 Global Climate Projections, Modeling, and Downscaling

The climate projections considered in this report represent a range of future greenhouse emission pathways (Reclamation, 2011d); however, uncertainties associated with estimating these pathways, including those introduced by assumptions of global growth and land use, are not explored in this analysis. Additional uncertainty is associated with feedbacks such as the influence of human-produced aerosols in the atmosphere.

GCMs themselves have associated uncertainty with respect to their initial conditions, inputs, representation of physical processes, and assumptions regarding the sensitivity of climate variables to changes in greenhouse gas concentrations and other parameters. Issues with GCMs are compounded by the fact that it is currently difficult, if not impossible, to validate GCM results using datasets that were not used to develop and tune these GCMs. Different simulations using the same model may have quite different realizations of longer timescale climate patterns. Regarding representation of physical processes, the most recent generation of GCM simulations (based on CMIP5) incorporate, in many cases, improved understanding of the climate system. By using both CMIP3- and CMIP5-based projections as part of the Klamath River Basin Study water supply assessment, we may evaluate the differences in results based on a wider range of model constructs. GCMs may have biases toward being too wet, too dry, too warm, or too cool, and these should be identified and accounted for in climate change impacts studies (Reclamation, 2011d). Although there is very high confidence that the CMIP5 models show long-term trends consistent with historical observations, there is substantial (several-fold) disagreement between models and observations over the rate of warming for 1998-2012. For example, Bindoff et al. (2013) acknowledge that the observed global mean surface temperature has shown a much smaller increasing linear trend over 1998-2012 than the suite of CMIP5 models, despite the fact that half of this period was included in the data that was used to develop/tune the models. Due to internal climate variability, in any given 15-year period the observed trend in the global mean surface temperature sometimes can lie near one end of a model ensemble.

The uncertainty due to the mismatch between simulated mean global surface temperature and observations is exacerbated by the fact that the reliability of model results declines and uncertainty expands as one goes from the global scale to finer (i.e., regional and local) scales as is necessary to do an analysis for the Klamath River Basin. This is particularly true for precipitation.

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(2) US Climate Change Science Program. Climate Models: An Assessment of Strengths and Limitations. Washington, DC: U.S. Climate Change Science Program and the Subcommittee on Global Change Research; 2008.

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Generally, to reduce inconsistencies between simulated climate and observed conditions, projections are bias corrected. The term bias correction refers to the use of a statistical procedure to adjust global climate model projections to remove differences between simulated and observed climate conditions computed over a common historical time period. This method, however, assumes that biases are systematic and their distributions over the historical time period would be similar to a future time period. Primary causes of bias in global climate model simulations include bias resulting from the coarse resolution of global climate models and the corresponding inability to resolve important stationary features such as land surface topography and land-water interfaces along coastlines and the use of simplified parameterizations to represent physical processes that occur at too small a scale or are too complex to be represented physically. They could also result from biases in emission inputs, coupled biogeochemical models and estimates of climate sensitivity. Model biases can significantly affect impact studies that use climate projections to evaluate hydrologic and ecosystem response to potential changes in climate. As a result, it is prudent to apply bias correction before using global climate model outputs as inputs to other types of models, recognizing that other uncertainties persist.

Uncertainties are also associated with the methodology used to downscale information at the scale of GCMs to the regional, or watershed, scale. The Klamath River Basin Study utilizes statistically downscaled climate projections to derive HDe climate scenarios. Although these types of scenarios have been used to support numerous water resources impacts studies, uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies, such as statistical downscaling, require historical reference information use on spatial climatic patterns at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which presumably would change somewhat with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption that the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have statistical stationarity. In actuality, it is possible that such stationarity will not hold at various space and time scales, over various locations, and for various climate variables. However, the significance of potential non-stationarity in empirical downscaling methods and the need to utilize alternative downscaling methodologies remains to be established.

3.9.2 Watershed Vegetation Changes under Climate Change

In Reclamation (2011d) and related literature sources cited, the chosen approach for assessing hydrologic effects under projected climate changes is to use a surface water hydrologic model that computes hydrologic conditions, given

changes in weather, while holding other watershed features constant. The composition of vegetation might change as climate changes, and that, in turn, would affect runoff through changes to evapotranspiration and infiltration processes.

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3.9.3 Direct Effects of Carbon Dioxide on Water Use in Vegetation

Increases in CO2 concentrations also affect vegetation growth, and water use and demand in a variety of other ways. Higher CO2 levels increase biomass production via an increase in the photosynthetic rate, unless there are nutrient limitations. They also increase the intrinsic water use efficiency (WUE) of plants, that is, they transpire (or discharge) less water to the atmosphere per unit biomass product. The latter then would decrease demand for irrigation water, and increase runoff, soil moisture and groundwater recharge, unless the transpiration effect is swamped by a countervailing increase in biomass production (AR5, WG2, Chapter 4, 276; IPCC 2014, 161). In managed systems, but not in unmanaged systems, the amount of biomass production can be controlled, and nutrient limitations on photosynthesis can be surmounted, if desired.

The IPCC notes that a meta-analysis of studies at 47 sites across five ecosystem types suggests that intrinsic WUE for mature trees increased by 20.5% between the 1970s and 2000s. It also notes that other studies have detected an increase in intrinsic WUE at several forest sites and a temperate semi-natural grassland since 1857 but the increase stopped in one boreal tree species after 1970 (AR5, WG2, Chapter 4, 294). In addition, a study of 21 forest sites in the Northern Hemisphere, including 7 unmanaged forests in the midwestern and northeastern U.S., found that carbon uptake and WUE had increased at the majority of sites for the periods examined (7-18 years) (Keenan et al. 2013). That study also found that observed increase in forest water-use efficiency was larger than predicted by existing theory and 13 terrestrial biosphere models.

Based on experimental results and modeling studies, the IPCC states that it has "medium confidence that increases in CO2 up to about 600 ppm will continue to enhance photosynthesis and plant water use efficiency (WUE), but at a diminishing rate" (AR5, WG2, Chapter 4, 287), and it classifies these effects as "first-order" influences on ecosystem and hydrological responses to anthropogenic climate change (AR5, WG2, Chapter 4, 288).

However, the IPCC notes that since "… water, carbon, and vegetation dynamics evolve synchronously and interactively under climate change, it remains a challenge to disentangle the individual effects of climate, CO2, and land cover change on the water cycle." (IPCC 2014, 160). Because of the complexities involved in modeling these effects, the Klamath River Basin Study did not factor changes in water demand, runoff, soil moisture and groundwater recharge due to the direct effects of CO2. Consequently, this is a substantial source of uncertainty that should be considered by users of this study.

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Sources:

1. AR5, WG2, Chapter 4.

2. IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summaries, Frequently Asked Questions, and Cross-Chapter Boxes. A Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. World Meteorological Organization, Geneva, Switzerland, 190 pp. 160 (See p. 160 for recharge).

3. Keenan TF, Hollinger DY, Bohrer G, Dragoni D, Munger JW, Schmid HP, Richardson AD. Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. Nature. 2013 Jul 18;499(7458):324-7.

3.9.4 Quality of Hydrologic Model Used to Assess Hydrologic Effects

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In Reclamation (2011d) and most of the cited literature sources, the chosen approach for assessing surface water hydrologic effects has typically involved using surface water hydrologic models, which may not represent key hydrologic processes related to groundwater and/or large water bodies. Reclamation (2011d) discusses these limitations, and they are illustrated in Section 3.3.2, Historical Surface Water Availability – Approach, which shows how the VIC model imperfectly reproduces historical runoff conditions. Some of these imperfections could be reduced through refined redevelopment, or calibration, of the model. Another approach for exploring the uncertainty associated with the VIC hydrologic model, which was not taken in this study, would be to apply additional surface water hydrology models and compare results across simulations.

In the case the Klamath River Basin, refinement of VIC model calibration is challenging due to the lack of available naturalized flow datasets. Reclamation (2005) showed the difficulty in developing naturalized flows in such a complex watershed. Additional efforts may be invested in this area; however, focusing on a change of projected future conditions relative to historical conditions is a scientifically defensible approach taken in numerous climate change impacts studies, and is the approach taken for the Klamath River Basin Study water supply assessment.

3.9.5 Quality of Groundwater Models Used to Assess Groundwater Effects

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Groundwater modeling in general is extremely challenging due to the complexity of most groundwater systems (the Klamath River Basin included) coupled with a general lack of sufficient data to characterize groundwater basins in great detail. The USGS has made great efforts in collecting data and developing a fine scale finite-difference MODFLOW model for the Upper Klamath Basin (Gannett et al., 2012). Despite the high level of effort taken in this study, significant uncertainties still remain about the adequacy of the model to characterize detailed groundwater dynamics in the basin. Gannett et al. (2012) discuss possible reasons for differences between observed and simulated groundwater elevations in parts of the basin, including lack of accurate information on rates and locations of pumping, and coarse vertical discretization of the model relative to the gradients of groundwater flow. Nonetheless, we may assume that historical biases in the MODFLOW model may carry through to the future. As such, we may evaluate the relative change of projected groundwater elevations and discharge compared with the historical simulation.

The Scott and Shasta Valleys have greater issues of data availability for characterizing the groundwater systems than the Upper Klamath Basin, where more resources have been invested in monitoring and evaluating the groundwater system. Monitoring wells are few and the monitoring data available for those wells is sparse, generally consisting of two or so measurements per year. In addition, CDWR Bulletin 118 was used to define groundwater basins in these regions, and these likely do not represent the complexity of groundwater aquifers that exist there. Development of groundwater models for these basins using this information poses a challenge. Furthermore, the size of these groundwater basins is much smaller than the Upper Klamath Basin, making the coarse spatial resolution of groundwater model inputs (such as precipitation, temperature, and gridded runoff) less relevant at the scale of these sub-basins. Due to these high levels of uncertainty, a statistical modeling approach was taken to simulate groundwater elevations in the Scott and Shasta Valleys. A simpler approach may be justified when uncertainty associated with input data is high. Still, the statistical models may be used to evaluate the relative change of projected groundwater elevations compared with estimated historical conditions.

3.9.6 Differences between Climate Projections from CMIP3 and CMIP5

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The above discussions of uncertainty related to climate forcings and downscaling techniques are based on analysis of projections from CMIP3. The models and scenarios of emissions used in CMIP5 differ in several ways from those used in CMIP3. First, model resolution has generally increased by a factor of 2 (i.e., CMIP5 models have, on average, twice the number of grid cells representing the atmosphere than CMIP3 models). Second, although many of the models used in CMIP5 are similar in structure to those used in CMIP3, many incorporate updated physics and added, or improved, individual process representation. Some of the models used in CMIP5 reflect a fundamental advancement in model structure by

incorporating biogeochemical cycling; this new class of models is referred to as Earth System Models. Third, there are notable differences in precipitation for some regions (e.g., greater warming over the Upper Columbia Basin, less precipitation over the northern Great Plains, and more precipitation over California and the Upper Colorado Basin). Projections showing wetter portions of California and the Upper Colorado are notable because they challenge the prevailing perspective of climate change impacts to the region that has been held since 2007 (informed by CMIP3 projections): namely, that these regions will become drier, resulting in reduced runoff. It is important to recognize that while CMIP5 offers new information, more work is required to better understand CMIP5 and its differences compared to CMIP3. In some regions, model resolution is likely the leading factor in these differences. In the North American Monsoon region, for example, the higher resolution of CMIP5 models allows these models to better capture the landward moisture transport and overland convection that results in monsoon precipitation events. These processes were not resolved in the lower resolution CMIP3 models.

The CMIP5 projections represent a new opportunity to improve our understanding of climate science, which is evolving at a rapid pace. While CMIP5 projections may inform future analyses, many completed and ongoing studies are informed by CMIP3 projections that were selected as the best information available at the time of the study. Even though CMIP5 provides the latest available suite of climate projections, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP3 projections. Current state of practice relies on one or both suites of climate projections for use in impacts studies.

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Chapter 4
Klamath River Basin Study
Assessment of Current and Future Water Demands

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Contents

Figures

Tables

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Chapter 4 Assessment of Current and Future Water Demands

4.1 Introduction

Changes in water demands in the Klamath River Basin over the next 50 years are uncertain, and will depend on a number of socioeconomic and other factors. The Klamath River Basin Study aims to assess the impacts of climate change on water supply and demand in the watershed from its headwaters to the mouth, and to identify current and projected water supply shortages. This chapter of the Klamath River Basin Study report quantifies current water demand and projected future water demand in a changing climate. Future demand projections are meant to be sufficiently broad to capture the plausible ranges of uncertainty. Projected water demands are evaluated along with the projected supply conditions in Chapter 3 as part of a system reliability analysis to identify potential water supply shortages in the Klamath River Basin, which is presented in Chapter 5. The system reliability analysis, presented in Chapter 6, identifies any potential shortfalls between demand and supply, as well as potential strategies to plan for and reduce gaps.

Statistically downscaled climate projections from general circulation models (GCMs) inform both the demand and supply analyses. As discussed in Chapter 3, two sets of downscaled GCM output were used in the analyses: Coupled Model Intercomparison Project Phase 3 (CMIP3) and Coupled Model Intercomparison Project Phase 5 (CMIP5). The main components of the Klamath River Basin Study and their interaction with developed climate change scenarios are shown in Figure 4-1. The ensemble hybrid delta (HDe) period change method (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d) described in Chapter 3 was used to assess the impacts of climate change on demands. The future periods used for the Klamath River Basin Study are the 2030s and 2070s (represented as the mean over 2020–2049 and 2060–2089, respectively) and the historical baseline period used for the analyses is 1950–1999.

Some of the analyses described in this chapter are based on previous work done as part of Reclamation's West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). WWCRA is a component of the Department of the Interior WaterSMART Program that was implemented to meet requirements of the Secure Water Act (Public Law 111-11, Sections 9501-9510).[6]

[6] http://www.usbr.gov/WaterSMART/wcra/index.html

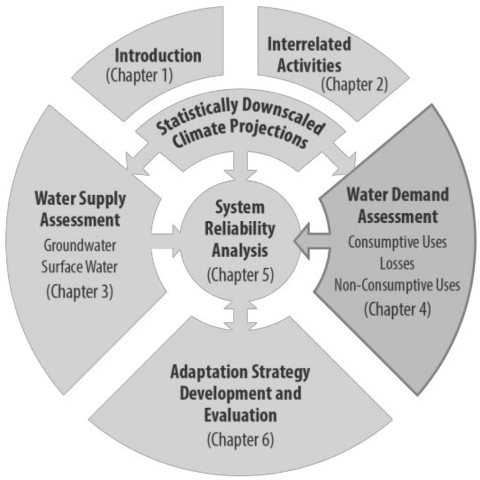

Figure 4-1. Overall approach of Klamath River Basin Study, highlighting Chapter 4

4.1.1 Description of Water Demands

Water demands are typically associated with one or more water uses that can be consumptive or non-consumptive. Consumptive water use results in a loss of water from the supply system, often associated with human activities. Examples of consumptive uses include manufacturing, agriculture, and food preparation where water is not returned to the supply system. Evaporation from water bodies such as reservoirs is another type of consumptive use that is more typically considered a loss. Non-consumptive uses are those which do not deplete the water supply. There are many types of non-consumptive uses; significant examples relevant to this study include hydropower generation, environmental resources, recreation, and aquaculture. Municipal and industrial (M&I) and rural domestic demands are typically comprised of both non-consumptive and consumptive uses. Another significant demand category relevant to the study is tribal demands, which are also comprised of both consumptive and non-consumptive uses.

Definition of Terms

Demand – Water needed to meet identified uses.

Consumptive Use – Water use resulting in a loss of available water supply, often associated with human activities.

Loss – Reduction of available water supply due to evaporation and operation inefficiencies.

Non-Consumptive Use – Water use not resulting in reduction of available water supply.

The focus of the Klamath River Basin Study is the assessment of current and future demands with respect to consumptive uses (both human-influenced and natural) and losses. Non-consumptive demands are either discussed qualitatively in this chapter or are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6.

4.1.2 Previous Studies

Many previous studies have quantified various types of water demand in all or part of the Klamath River Basin. Table 4-1 identifies the references that were reviewed in development of the water demands assessment. In the case of agricultural irrigation and reservoir evaporation, we utilized methods described by Reclamation (2014) in order to maintain consistency with approaches used in other western U.S. watersheds.

The following sections discuss current and future water demands, and detail how previous studies were used and whether the analysis was quantitative or qualitative.

Table 4-1. Summary of demand categories and related previous studies

Demand Categories	Primary Information Source(s)	Domain
Human Influenced Consumptive Uses		
Agricultural irrigation	Reclamation WWCRA (2014)	Western U.S.
		U.S. Counties
	HDR (2008)	Oregon
	CDWR (2009)	California
	Cuenca (1992)	Upper Klamath Basin (Oregon)
	Gannett et al. (2007)	Upper Klamath Basin
	Reclamation (2005b)	Klamath Project area
Municipal & Industrial	CDM (2010)	Klamath Falls, OR
	SHN (2004)	Hayfork, CA
	Pace (2011)	Weaverville, CA
	Pace (2004)	Weed, CA
	Tully and Young (2010) and Pace (2006)	Yreka, CA
	The USGS Water Use Program (http://water.usgs.gov/watuse/; Kenny et al., 2009)	U.S. Counties
	HDR (2008)	Oregon
	CDWR (2009)	California
Rural Domestic	USGS Water Use Program	U.S. Counties
Tribal	Interior and CDFG (2012)	

Table 4-1. Summary of demand categories and related previous studies

Demand Categories	Primary Information Source(s)	Domain
Other Consumptive Uses and Losses		
Wetlands	Stannard et al. (2013)	Upper Klamath Basin
	Mayer and Thomasson (2004)	Lower Klamath NWR
	Bidlake (2002)	Tule Lake NWR
Evaporation from lakes and reservoirs	Reclamation WWCRA (2014)	Western U.S.
	Bidlake (2000), Bidlake and Payne (1998), Janssen and Cummings (2007), and Stannard et al. (2013)	
Non-Consumptive Uses		
Environmental Resources	See Section 4.2.3.2, Environmental	
Hydropower	See Section 4.2.3.3, Hydropower	
Recreation	See Section 4.2.3.1, Recreation	
Aquaculture	See 4.2.3.4, Aquaculture	

4.2 Current Demands

Historical and current consumptive water uses and losses were quantified through findings from previous studies and model simulations and evaluated in order to compare with potential future changes due to climate change. Non-consumptive uses are briefly discussed; however, these uses are quantified in the modeling supporting the system reliability analysis in Chapter 5. Identified non-consumptive needs are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6. The current demands considered in this chapter are listed in Table 4-2 along with the sources or models used to provide an estimate for the Klamath River Basin Study. Each of the demands evaluated in this chapter, and the associated estimates used, are discussed in the sections that follow.

Current Human Influenced Consumptive Uses

Based on analyses supporting the Klamath River Basin Study, total consumptive water demand for human uses in the basin is about 800,000 acre-feet/year and about 98 percent of the total human influenced demand is for agricultural irrigation.

4.2.1 Human Influenced Consumptive Uses

Consumptive uses for human needs in the Klamath River Basin Study demands assessment have been quantified using a variety of existing sources as well as

model simulations. Table 4-2 summarizes the categories for which demands have been quantified, showing primary sources of data and models used.

One existing source of consumptive use information, which was used in conjunction with other sources described later, is the countywide USGS Water Use Program data. This is arguably the most comprehensive source of existing water use information for the study area (including both consumptive and non-consumptive uses). The most current data available are typically for 2005 and 2010, but more recent data were available in a few cases.

Current Human Influenced Consumptive Use Estimate Sources

Human influenced consumptive use estimates are based in part on USGS data, but this study uses WWCRA based model simulations for agricultural demands

Table 4-2. Summary of demand categories evaluated by the Klamath River Basin Study Assessment of Current and Future Water Demands and data and methods used

Demand Categories	Data Sources Used	Methods Used
Human Influenced Consumptive Uses		
Agricultural irrigation	Reclamation WWCRA (2014)	ET Demands Model (further described in corresponding section)
Municipal & industrial	Municipal water plans and USGS Water Use Program (see references in Table 4-1)	Statistical models and historical information
Rural domestic	USGS Water Use Program	Statistical models and historical information
Tribal	Addressed as part of agricultural, M&I, and Rural Domestic demand categories	
Other Consumptive Uses and Losses		
Wetlands	Stannard et al. (2013)	ET Demands Model and empirical relationships
Evaporation from lakes and reservoirs	Reclamation WWCRA (2014)	Complementary Relationship Lake Evaporation (CRLE) model

Included in Table 4-3 are 2005 USGS usage estimates for Siskiyou and Trinity Counties in California, Klamath County, Oregon, and the portion of Modoc County, California within the Klamath River Basin.[7] The total basin demand is approximately 1.2 million acre-feet per year (AFY). Note that Table 4-3 values are not all-inclusive since Del Norte and Humboldt Counties in the California portion of the basin are not included. Estimates for these counties are not

[7] http://water. usgs.gov/watuse/

included since only a very small portion of their water demands (estimated between 1 and 2 percent) occur within the basin. The in-basin demands for these counties are discussed later under the specific demand category discussions. Also note that the USGS data do not include reservoir evaporation. Additionally, the uses reported in Table 4-3 include both consumptive and non-consumptive components of these uses. For example, municipal and industrial (M&I) use includes water that eventually returns to the river system via a wastewater treatment plant.

Table 4-3. Summary of USGS 2005 Water Use Program estimates for the Klamath River Basin

Water Use Category (note: includes both consumptive and non-consumptive uses)	2005 Use (AFY)
Surface water irrigation	717,154
Groundwater irrigation	433,164
Municipal and industrial	18,204
Rural domestic	11,255
Livestock	2,903
Mining and industrial/commercial	2,868
Total (human influenced uses)	**1,185,548**

Source: USGS Water Use Program

The Klamath River Basin Study estimates of current human influenced consumptive uses in the watershed are based in part on the USGS Water Use Program data summarized above. However, in the case of agricultural irrigation demand (surface and groundwater), this study utilizes model simulations of agricultural water requirements following the approach of Reclamation's West Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). In the case of M&I and rural domestic water uses, more current (2010) estimates were made based on historical population trends. Also, the study focuses only on the consumptive portion of these demands, which is assumed to be 40 percent for both M&I and rural domestic demands and comprised of landscape irrigation (refer to Section 4.2.1.2, Municipal and Industrial).

Estimated current consumptive uses (including human influenced uses, wetland ET, and reservoir evaporation losses) by the Klamath River Basin Study are summarized in Table 4-4. These are estimated basin-wide uses that are the basis for assessment of projected changes in consumptive uses and losses for the two future time periods considered in this study, the 2030s and 2070s. Respective sections of this chapter provide details behind these estimates and the associated assumptions made. Note that the estimated reported M&I and rural domestic consumptive uses (see Table 4-4) are approximately 40 percent of the values reported by the USGS Water Use Program (see Table 4-3), which supports the

assumption by the Klamath River Basin Study regarding the consumptive portion of total M&I and rural domestic demand.

Table 4-4. Estimated current basin-wide consumptive uses and losses as computed by the Klamath River Basin Study

Basin Wide Consumptive Uses and Losses	Estimated Mean Annual Quantity (AFY)
Agricultural irrigation (NIWR)	755,734
Municipal and industrial	8,801
Rural domestic	4,537
Subtotal for Human Influenced Consumptive Use	**769,072**
Wetland ET	1,089,061
Reservoir and lake evaporation	181,297
Total Consumptive Uses and Losses	**2,039,430**

4.2.1.1 Agricultural Irrigation

Irrigation of croplands is by far the largest human influenced consumptive use in the Klamath River Basin, 97 percent[8] according to the USGS Water Use Program estimates (which include conveyance and on-farm losses) and approximately 98 percent[9] according to the Klamath River Basin Study estimates (which do not include conveyance and on-farm losses). Agricultural irrigation use typically includes crop demands, conveyance losses, and on-farm losses. Conveyance and on-farm losses are a function of methods employed to convey water to the croplands (open channels, pipe, etc.) and to apply irrigation water (flood, sprinklers, etc.). Given the numerous variables associated with conveyance and on-farm losses, these losses were not calculated in this study.

> **ET Demands Model Methodology**
>
> The model calculates historical and future daily net irrigation water requirements using the FAO-56 dual crop coefficient method with crops, temperature, precipitation, wind, and soil inputs. Solar radiation and humidity are estimated from daily minimum and maximum temperature inputs.

Crop demands are consumptive. Conveyance and on-farm losses can be consumptive or non-consumptive. Examples of non-consumptive conveyance and on-farm losses include field runoff and deep percolation, since associated water generally returns to the supply system. An example of a conveyance or on-farm loss that is

8 Computed as sum of 717,154AFY and 433,164AFY, divided by 1,185,548AFY (refer to Table 4-3).

9 Computed as subtotal for human influenced consumptive uses 755,734AFY, divided by 769,072AFY (refer to Table 4-4).

consumptive is evapotranspiration by natural vegetation on farm lands or in and around canals.

This study focuses on the crop demands, or crop net irrigation water requirement (NIWR). NIWR is equal to the total crop demand minus that amount of the crop demand that is met by precipitation, i.e., effective precipitation (P_e). NIWR does not include conveyance or on-farm losses. Crop water demand is a function of evapotranspiration (ET), which is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Allen et al., 1990). Crop water demand also does not include conveyance or on-farm losses.

Current NIWR estimates have been developed for this study. A discussion of recent irrigation demand estimates is presented first, followed by a discussion of the developed NIWR estimates.

Recent Irrigation Estimates by Others
Estimates by others are presented as background information and for comparison to those developed in the Klamath River Basin Study. As discussed previously, the USGS estimates that total irrigation water use for the basin in 2005 was 1,150,318 AF, including 717,154 AF from surface water sources and 433,164 AF from groundwater sources (Kenny et al., 2009). These estimates include irrigation of golf courses, parks, nurseries, cemeteries, and other self-supplied landscape-watering uses. The USGS estimates also include conveyance and on-farm water losses. Detailed information on how the USGS developed the 2005 irrigation estimates is provided in Dickens et al. (2011).

> **Current Agricultural Irrigation Demand**
>
> Agricultural irrigation demands, in the form of net irrigation water requirement (NIWR), were simulated by the ET Demands model using current cropping data and average climate conditions for the period 1950–1999.

The CDWR estimates crop irrigation demands annually for the California portion of the Klamath River Basin (the Klamath Upper and Lower Planning Sub-area).[10] The CDWR estimates include NIWR and total water applied, which includes on-farm losses but not conveyance losses. The reported 2010 estimates for the California portion of the basin are 347,672 AF of NIWR and 482,504 AF total water applied (Coombe, 2013). It is estimated that approximately 62 percent of the total demand is met with surface water and 38 percent is met with groundwater sources.

The OWRD's recent Statewide Water Needs Assessment (HDR, 2008) includes a 2010 agricultural irrigation water use estimate for Klamath County, Oregon,

[10] http://www.water.ca.gov/landwateruse/anlwuest.cfm

which represents the approximate Oregon portion of the basin. The estimate is 730,000 AF and includes both on-farm and conveyance losses.

The sum of CDWR and OWRD estimates (1,212,504 AF) is greater than, though comparable to, the USGS estimate for total irrigation (1,150,318 AF). It is assumed the discrepancies are associated with which loss estimates were included and how they were estimated.

Estimation of Net Irrigation Water Requirements

Current and future NIWR estimates were developed for this study following the methods established by Reclamation's WWCRA. Brief descriptions of these methods follow and more detailed discussions are contained in Reclamation (2014).

The current or baseline irrigation water demand estimates developed for this study are based on the most recent available crop data and climate conditions during the historical baseline period 1950 through 1999. Crop types and quantities reported for 2009 were provided by the Klamath Basin Area Office for Reclamation's Klamath Project lands, and crop data for the remainder of the basin were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service as reported for 2010.[11] The 1950 through1999 climate data used are from the same published data set by Maurer et al. (2002) discussed in Chapter 3. The values used from this data set were adjusted based on historical observations from 13 weather stations located near the irrigated crop areas to remove any biases that may exist between the gridded meteorological dataset (Maurer et al., 2002) and these point observations.

NIWR estimates were calculated for each of the basin's twelve Hydrologic Unit Code eight-digit level drainage areas (HUC8 sub-basin). The HUC8 sub-basins are shown in Figure 4-2. The map also includes the estimated number of irrigated acres by HUC8 sub-basin. Point locations in the figure represent corresponding weather stations used to support the modeling effort, including those used for removing biases in the gridded meteorological dataset and those used for estimating dewpoint and windspeed across the HUC8 sub-basins. Table 4-5 provides additional details for some of these features. A full summary of weather station information is provided in Appendix C, Section 2.0. Appendix C, Section 3.0 summarizes the estimated percentage of crop acreage within each HUC8 sub-basin according to crop type.

[11] http://www.nass.usda.gov/research/Cropland/SARS1a.htm

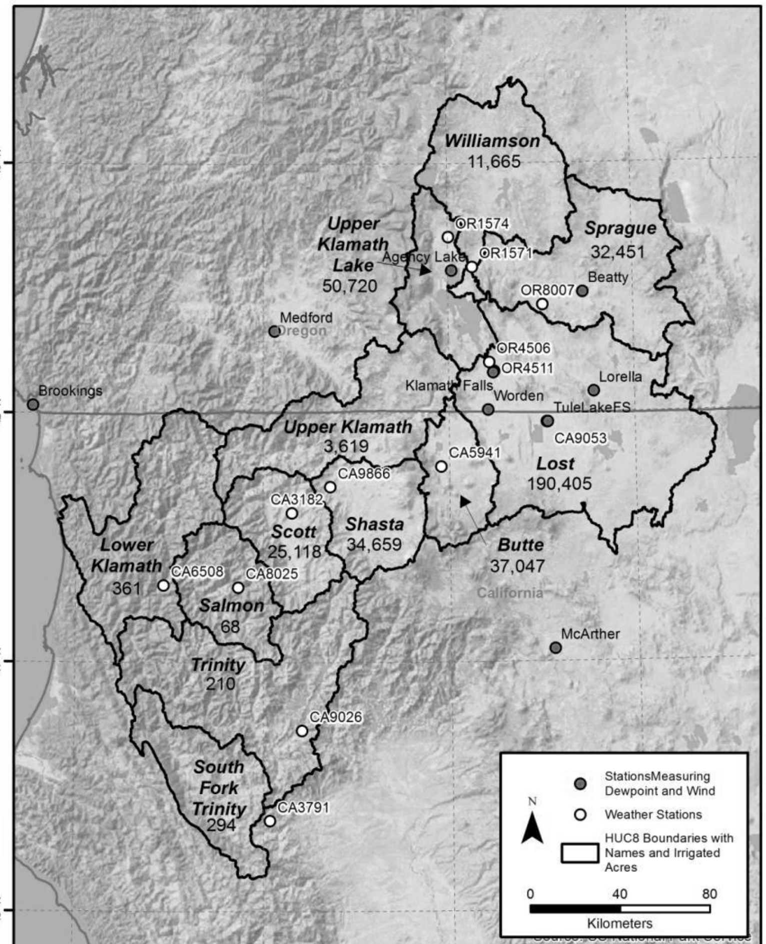

Figure 4-2. Klamath River Basin – HUC8 Sub-basins, irrigated acres, and weather stations used to simulate baseline and projected irrigation demands

Table 4-5. Irrigated land totals and weather stations associated with HUC8 sub-basins

HUC8 Name / Number	Weather Station Name(s)	Irrigated Acres
Williamson / 18010201	Chiloquin	11,665
Sprague / 18010202	Sprague River 2 SE	32,451
Upper Klamath Lake / 18010203	Chiloquin NW	50,720
Lost River / 18010204	Tule Lake and Klamath Falls	190,405
Butte /18010205	Mount Hebron	37,047
Upper Klamath / 18010206	Klamath Falls 2 SSW	3,619
Shasta /18010207	Yreka	34,659
Scott / 18010208	Fort Jones	25,118
Lower Klamath / 18010209	Orleans	361
Salmon / 18010210	Sawyers Bar	68
Trinity / 18010211	Trinity River Hatchery	210
South Fork Trinity / 18010212	Harrison Gulch	294
Total Irrigated Acres		**386,616**

Estimates of NIWR were developed using the ET Demands model, originally developed by the University of Idaho, Nevada Division of Water Resources, and the Desert Research Institute (DRI). Recent modifications to the model for WWCRA applications were made through a collaborative effort by Reclamation, DRI, and the University of Idaho (Reclamation, 2014).

The ET Demands model is based on the Penman Monteith (PM) dual crop coefficient method (Allen et. al, 1998). The American Society of Civil Engineers (ASCE) has adopted the FAO-56 PM equation as the standardized equation for calculating reference ET (ET_o) (ASCE, 2005). The short grass reference crop version of the PM equation was used to be consistent with previous Reclamation work.

By using the PM dual crop coefficient method rather than a single crop coefficient approach, transpiration and evaporation are accounted for separately to better quantify evaporation from variable precipitation and simulated irrigation events. This also allows accounting of winter soil moisture conditions, which can be a significant factor when estimating early irrigation season NIWR. The dual crop coefficient method provides a robust means for estimating NIWR based on continuous accounting of soil moisture balance.

The ET Demands model first calculates daily ET_o for each HUC8 sub-basin as a function of maximum and minimum daily air temperature (T_{max} and T_{min}) from the 1950–1999 climate data set mentioned above. The PM equation variables of vapor pressure, solar radiation, and wind speed are empirically estimated as described in Reclamation (2014) per the methods recommended by ASCE (2005). Figure 4-3 shows the spatial distribution of mean daily historical baseline

temperature, precipitation, dewpoint depression,[12] and wind speed (lower right) values used in the model. The historical baseline precipitation and temperature values for each HUC8 sub-basin are included in the model results summary tables provided in Appendix C, Section 1.0. The Figure 4-3 windspeed and dewpoint depression panels include the point locations of weather stations used as the basis for estimating these values for HUC8 sub-basins (see also Figure 4-2 and Appendix C, section 2.0).

Figure 4-3 illustrates warm to cool mean annual temperatures from west-southwest to northeast, respectively, while precipitation varies from moderately high to low amounts from southwest-central to northeast, respectively. The spatial distribution of mean annual dewpoint depression clearly shows northeast areas are more arid while southwest-central areas are more humid. The spatial distribution of mean annual wind speed generally exhibits lower wind speed in west and southwest areas, with higher wind speed in the northeast portion of the basin.

Weighted average soil conditions (including allowable water content and percent clay, silt, and sand) for the irrigated lands in each HUC8 sub-basin were input to the ET Demands model. The soils information is based on data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (USDA-SCS, 1991). The soil parameters affect the estimation of irrigation scheduling, evaporation losses from soil, deep percolation from root zones, antecedent soil moisture condition, and runoff from precipitation.

[12] Dewpoint depression is equal to T_{min} minus dewpoint temperature and is used to estimate vapor pressure or humidity values.

[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

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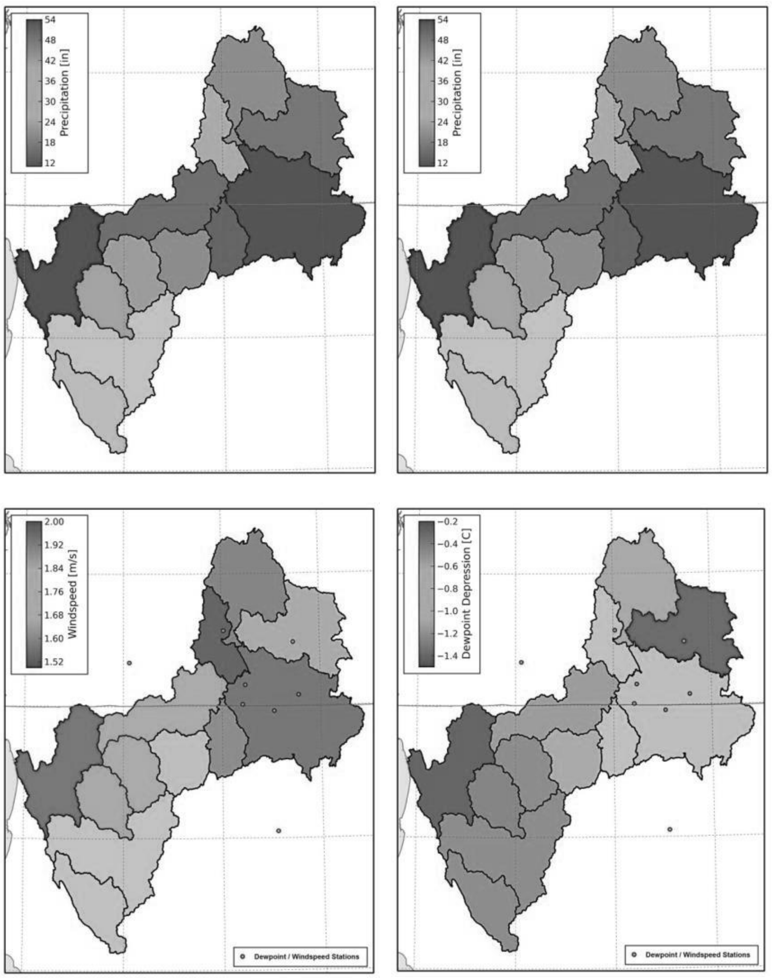

Figure 4-3. Spatial distribution of historical baseline (1950–1999) mean annual temperature, precipitation, windspeed, and dewpoint depression

The daily net or actual ET (ET_c) is then calculated as a function of the two primary crop coefficients and a crop stress coefficient. ET_c for all crop types within a given HUC8 was estimated as follows:

$$ET_c = (K_s K_{cb} + K_e) ET_o$$

where ET_o is the ASCE-PM grass reference ET, K_{cb} is the basal crop coefficient, K_e is the soil water evaporation coefficient, and K_s is the stress coefficient. K_{cb} and K_e are dimensionless and range from 0 to 1.4. Daily K_{cb} values over a season, commonly referred to as the crop coefficient curve, represent impacts on crop ET from changes in vegetation phenology, which can vary from year to year depending on the start, duration, and termination of the growing season, all of which are dependent on temperature. K_e is a function of the soil water balance in the upper 0.1 meter of the soil column, since this zone is assumed to be the only layer supplying water for direct evaporation from the soil surface. K_s ranges from 0 to 1, where 1 equates to no water stress, and is also dimensionless. A daily soil water balance for the simulated effective root zone is required and computed in ET Demands to calculate K_s. In the case of computing the ET_c and NIWR, K_s is generally 1 but can be less than 1 in the winter if precipitation is low and winter surface cover is specified to be anything other than bare soil, such as mulch or grass.

Values of K_{cb} for a given crop vary seasonally and annually to simulate plant phenology as impacted by solar radiation, temperature, precipitation, and agricultural practice. Seasonal changes in vegetation cover and maturation are simulated in the ET Demands model by each crop specific K_{cb} as a function of air temperature. This is expressed in terms of cumulative growing degree days (GDD). After planting of annuals or the emergence of perennials, the value of K_{cb} gradually increases with increasing temperatures until the crop reaches full cover. Once this happens, and throughout the middle stage of the growing season, the K_{cb} value is generally constant or is reduced due to simulated cuttings and harvest. From the middle stage to the end of the growing season the K_{cb} value reduces to simulate senescence. GDD is calculated in the ET Demands model by three different methods as described in Reclamation (2014). The GDD equations' constants were calibrated based on historical data (green-up or planting, timing of full cover, harvest, and termination dates).

Having the ability to simulate year to year variations in the timing of green-up or planting, timing of effective full cover, harvest, and termination, is necessary for integrating the effects of temperature on growing season length and crop growth and development, especially under changing climate scenarios.

The NIWR rate or depth is calculated in the ET Demands model by factoring in P_e (NIWR = $ET_c - P_e$). P_e is calculated as a function of daily precipitation (from the climate data set), antecedent soil moisture, and precipitation runoff. Soil moisture is a function of the moisture holding capacity of the weighted average soil type input to the model for each HUC8 sub-basin. Precipitation runoff is calculated based on daily precipitation using the NRCS curve number method (USDA-SCS, 1972).

Simulation of irrigation events by the ET Demands model occurs when the crop root zone moisture content drops to the crop specific maximum allowable depletion threshold. Irrigations are specified to fill the root zone by the difference between field capacity[13] and the cumulative soil moisture depletion depth amount.

The NIWR and ET_c rates for each crop within a given HUC8 sub-basin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 sub-basin and all crop values are summed to calculate weighted average HUC8 sub-basin NIWR and ET_c rates, as shown in the equation below.

$$HUC8\ subbasin\ rate\ = \sum_{i=1}^{i=n} crop\ ratio\ i * crop\ rate\ i$$

The product of the weighted average NIWR and the total irrigated acreage yields the NIWR volume for each HUC8 sub-basin in acre-feet. A similar approach is used to calculate the ET_o, ET_c, and NIWR estimates for the entire Klamath River basin where the ratios of sub-basin to basin irrigated acres are applied to the sub-basin values and the average of the weighted values is calculated. Crop types and corresponding percentages of total crop acreage by HUC8 sub-basin are provided in Appendix C, Section 3.0.

The ET Demands model results for baseline conditions include ET_o, ET_c, NIWR rate, and NIWR volume for each HUC8 sub-basin. The annual average values for 1950–1999, which represent the historical baseline or current conditions for the purpose of this study, are summarized in Table 4-6. Graphical representations of these values are provided in Figure 4-4. Spatial distributions of ET_o, ET_c, and NIWR depth ranges from 41 to 51, 29 to 52, and 18 to 37 inches per year, respectively, with higher rates occurring in the northeast portion of the basin where growing season air temperature, solar radiation, and dewpoint depression are significantly larger relative to the southwest-central portion of the basin. NIWR volumes range from 197 AFY in the Salmon HUC8 sub-basin, where there is very little irrigated land, to 329,469 AFY in the Lost River HUC8 sub-basin where the majority of Reclamation's Klamath Project irrigated lands are located.

[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

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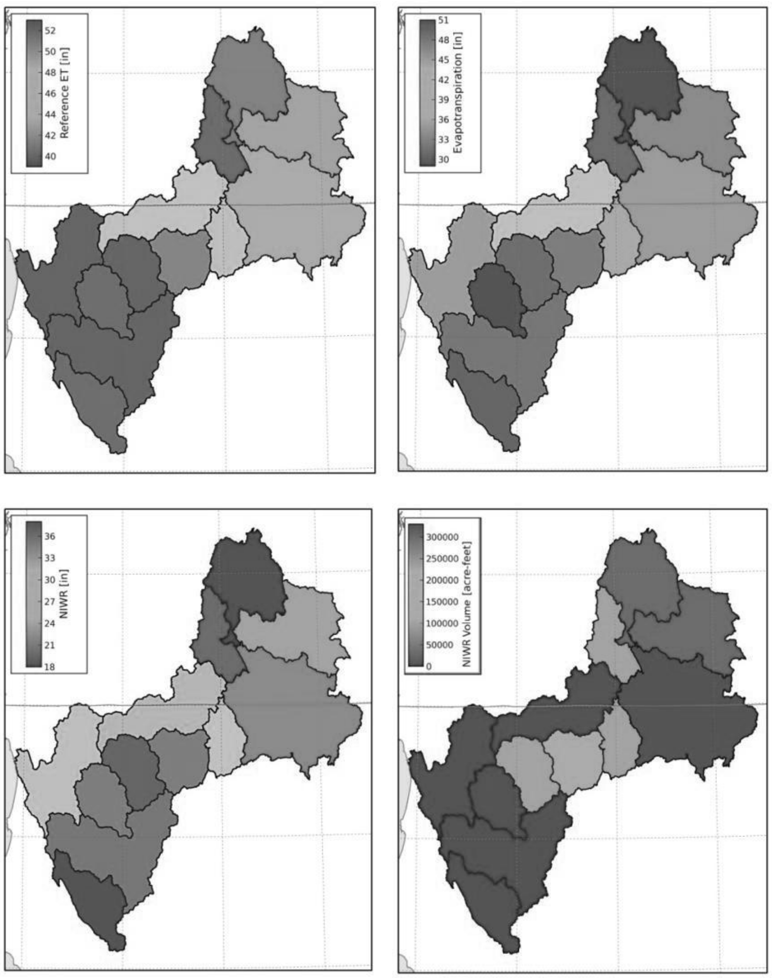

Figure 4-4. Spatial distribution of baseline reference evapotranspiration, crop evapotranspiration, net irrigation water requirement depth, and NIWR volume

Table 4-6. Summary of baseline reference evapotranspiration, crop evapotranspiration, and net irrigation water requirement rates and volumes

HUC Sub-basin	ET_o (in/year)	ET_c (in/year)	NIWR Rate (in/year)	NIWR Volume (AFY)
Williamson	40.8	29.4	18.0	17,513
Sprague	42.3	29.5	20.4	55,216
Upper Klamath Lake	39.9	30.4	18.7	79,101
Lost River	43.3	34.1	20.2	329,469
Butte	46.9	36.5	27.2	83,976
Upper Klamath	45.4	40.9	30.7	9,255
Shasta	50.5	47.9	35.1	101,460
Scott	52.3	49.0	36.8	77,114
Lower Klamath	52.2	44.6	29.5	887
Salmon	52.0	50.6	35.0	197
Trinity	52.3	48.6	35.9	628
South Fork Trinity	51.8	49.6	37.4	917
Averages & Total NIWR Vol.	**47.5**	**40.9**	**28.7**	**755,734**

Notes: ETo = reference evapotranspiration; ETc = crop evapotranspiration; NIWR = net irrigation water requirement

Table 4-7 provides a summary of the basin total NIWR from Table 4-6 and the previous irrigation estimates by USGS, CDWR, and OWRD. As discussed previously, the USGS and OWRD estimates include conveyance and application losses; the CDWR estimate includes application losses; and the USGS estimate includes irrigation demands for other uses in addition to agricultural irrigation (e.g., golf courses, parks, etc.). Depending on local conditions, significant conveyance and application losses are considered consumptive uses when providing water sources for riparian and wetland plants and sources of evaporation.

The ratio of the basin study estimate (755,734) to the USGS estimate (1,150,318) implies the overall average efficiency of the irrigation systems is approximately 66 percent, which is reasonable. The USGS estimate (1,150,318) is within 5.1 percent of the sum of the QWRD and CDWR estimates (730,000 + 482,504 = 1,212,504).

Table 4-7. Summary of irrigation demand estimate developed for this study and previous estimates by others

Description	Annual Volume (AFY)
Basin total crop net irrigation water demand estimated in Klamath River Basin Study	755,734
Basin total irrigation demand from 2005 USGS Water Use Program	1,150,318
OWRD 2010 estimate of crop irrigation demand for the Oregon portion of the basin	730,000
CDWR 2010 estimate of crop irrigation demand for the California portion of the basin	482,504

4.2.1.2 Municipal and Industrial

This category includes water demands that are met by public water supply systems that range in size from 15 connections[14] to many thousands of connections. The estimates are typically based on the supplier's production quantities, which include water delivered to customers plus leakage and other unaccounted for water. M&I customers include domestic households, industrial facilities, and commercial businesses.

Basin-wide total M&I use, shown in Table 4-3, is 18,204 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, which are entirely within the Klamath River Basin. Modoc, Humboldt, and Del Norte Counties each have small fractions within the Klamath River Basin. Most of the Humboldt and Del Norte County systems serve tribal communities. Note that within the California portion of the basin there is one small M&I system in Modoc County; there are four small systems in Humboldt County, and seven small systems in Del Norte County. Information on these California county systems is discussed later in this section.

Per capita total use estimates for the three counties entirely within the Klamath River Basin were calculated from the USGS data by dividing annual use by the reported population served. These estimates are summarized in Table 4-8.

Table 4-8. Per capita total M&I water use estimates from USGS 2005 data (including consumptive and non-consumptive portions)

County, State	Per Capita Rates (gpcd)
Siskiyou , California	468
Trinity , California	146
Klamath , Oregon	188

Source: USGS

[14] The Safe Drinking Water Act, Section 1401(4) defines a public water system as that delivering water for human consumption to not less than 15 service connections or 25 regularly served persons.

The Siskiyou County per capita total M&I water use reported in 2005 by the USGS is much higher than for Klamath County and Trinity County. Further, review of near current total M&I use from recent planning studies for Weed and Yreka suggest this value to be outside the estimated range for the two largest municipalities in Siskiyou County.

Water plans were reviewed for the four largest municipalities in the Klamath River Basin which include Weed and Yreka in Siskiyou County, California, Weaverville in Trinity County, California, and Klamath Falls in Klamath County, Oregon. Most of the entities that provide M&I service to the smaller municipalities in Del Norte, Humboldt, and Modoc Counties were contacted for recent water use data, as they do not have municipal water plans. These include Willow Creek, Orleans, and Hoopa in Humboldt County, California, Newell in Modoc County, California, and Klamath in Del Norte County, California. Current annual water use for these municipalities is summarized in Table 4-9. Similar to uses identified by municipal water plans, these uses include both consumptive and non-consumptive components.

It should be noted that reported M&I uses typically include both consumptive and non-consumptive components. In the Klamath River Basin Study, those reported M&I uses that include both components are described as total M&I use. This study focuses only on the consumptive portion of M&I use and assumes that 40 percent of total M&I use is consumptive and is used for landscape irrigation, with the remaining 60 percent becoming wastewater effluent. In this section we distinguish between total M&I use and consumptive M&I use, where practicable.

M&I and Rural Domestic Consumptive Use

Approximately 75 percent of the M&I demand within the Klamath River Basin is from the four largest municipalities (Klamath Falls, OR; Weed, CA; Yreka, CA; Weaverville, CA). Annual rural domestic uses represent approximately 0.4 percent of total basin demand.

Based on Mayer et al. (1999) and given that the majority of the basin's population is located in warmer-drier areas, it appears 40 percent is a reasonable average value for the basin. Mayer et al. (1999) reports the findings of a residential water use study that included 1,188 households in 12 North American cities. The reported range of outdoor use as the percentage of total use is 22 to 67 percent, with a range of 22 to 38 percent for wetter climates. Also, the U.S. Environmental Protection Agency WaterSense Program website[15] reports that one-third of U.S. residential water use is for landscape irrigation.

[15] http://www.epa.gov/WaterSense/pubs/outdoor.html

Table 4-9. Summary of total M&I use for significant municipalities

Location	Annual Use (AFY)	Per Capita Demand (gpcd)	Reference
Klamath Falls, OR (Klamath County)	9,428 (2010 est)	167 (1998-2007est)	CDM (2010)
Yreka, CA (Siskiyou County)	2,243 (2010 est)	280-325 (2011 est)	Pace (2006), Tully and Young (2011)
Weed, CA (Siskiyou County)	994 (2010 est)	NA	Pace (2004)
Weaverville, CA (Trinity County)	841 (2010 est)	NA	Pace (2011)
Total of Above Annual Demands	**13,506**[16]		
Newell, CA (Modoc County)	188	194	2003 CDWR funding application (Hammond Engineering, 2001)[17]
Willow Creek, CA (Humboldt County)	767	401	Personal communication[18]
Hoopa, CA (Humboldt County)	565	168	Personal communication[19]
Orleans, CA (Humboldt County)	153 (OCSD) 50 (OMWC)	319 (OCSD) 529 (OMWC)	Personal communication[20]
Klamath, CA (Del Norte County)	166 (est)	150 (est)	Personal communication[21]
Total of Above Annual Demands	**1,889**		

Comparison of the total for the four large municipalities (13,506 AF) to the USGS reported 2005 M&I total (18,204 AF) indicates approximately 75 percent of the M&I demand within the majority of the basin (Klamath County, Oregon and Trinity and Siskiyou Counties in California) is from these municipalities and the other approximately 25 percent is made up by the smaller M&I systems. The Klamath River Basin Study estimates 2010 total M&I use as the sum of use in

[16] Compare with USGS total demand for Klamath, Siskiyou, and Trinity Counties of 18,204 AFY. The comparison shows that demands from the four major municipalities comprise about 75 percent of the total demand in these three counties.

[17] CDWR funding application reports an annual use of 188 AFY and a 1999 service population of 866. This yields a per capita demand rate of 194 gpcd.

[18] Mr. Lonnie Danel, Administrator (personal communication, November 8, 2013). The 2012 approximate annual use for the Willow Creek Community Service District is 767 AF. Based on the 2010 census population for Willow Creek (1,710) this use yields a per capita demand of 401 gpcd.

[19] According to Mr. Murphy Lott, Operator for Hoopa Public Utilities District, Humboldt County, California (personal communication, November 12, 2013), the 2012 total use for the District's service area was approximately 565 AFY. Based on the reported service area population of approximately 3,000, the per capita average demand is 168 gpcd.

[20] Orleans, California in Humboldt County is served by two public water systems. Debbie Mace of the Orleans Community Service District (OCSD) reports (personal communication, December 5, 2013) approximate annual total M&I usage is 153 AFY serving a population of 430. This equates to a per capita demand of 319 gpcd. Jim Slusser of the Orleans Mutual Water Company (OMWC) reports (personal communication, December 5, 2013) approximate annual total usage is 50 AFY serving a population of 85. This equates to a per capita demand of 529 gpcd.

[21] Ms. Jan Chinook (personal communication, November 12, 2013) with the Klamath, California Chamber of Commerce reports there are seven public water systems serving this community in Del Norte County. The approximate population served by these systems is reported to be 985. Three of seven operators that were successfully contacted reported their systems are not metered. Given the lack of data and the generally transient service population, per capita demand was assumed (150 gpcd) to estimate an annual total M&I use of 166 AFY.

Klamath, Siskiyou, and Trinity Counties, plus uses identified in the small municipalities of Modoc, Humboldt, and Del Norte Counties.

As stated above, an estimated 40 percent of total M&I use is for landscape irrigation. This fraction is considered 100 percent consumptive. The remaining 60 percent of the total M&I use is considered non-consumptive and is assumed to return to receiving waters as wastewater effluent. The computed basin-wide M&I consumptive use of 8,801 AFY is the baseline M&I consumptive use for the Klamath River Basin Study (see Table 4-4). The M&I uses that comprise the Klamath River Basin Study estimate of basin-wide current annual consumptive use are provided in Table 4-10.

Table 4-10. Summary of total and consumptive M&I uses for the Klamath River Basin Study

Location	Annual M&I Use (AFY)
Klamath County	9,736
Siskiyou County	7,286
Trinity County	3,093
Small municipalities of Modoc, Humboldt, and Del Norte Counties	1,889
Basin Wide Total M&I Use	22,004
Basin Wide Consumptive M&I Use	8,801

4.2.1.3 Rural Domestic

The estimate of basin-wide rural domestic use shown in Table 4-3 is 11,255 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, plus a portion of the reported demand for Modoc County. The Modoc County estimate was calculated as the product of the reported use for the county and the ratio of the estimated population within the basin to the total county population. It is assumed the limited number of rural domestic water users in the portions of the basin in the counties of Del Norte and Humboldt in California and Lake and Jackson in Oregon are negligible. Based on these data and excluding hydropower and lake and reservoir evaporation, annual rural domestic uses represent approximately 0.4 percent of total basin demand. Note that, similar to M&I use, the rural domestic use reported by the USGS includes both consumptive and non-consumptive components. The Klamath River Basin Study assumes that 40 percent of total rural domestic use goes to landscape irrigation and is entirely consumed. (See discussion and references to Mayer et al. (1999) and the WaterSense program[22] above under Section 4.2.1.2, Municipal and Industrial.) The remaining 60 percent of the total rural domestic use is assumed to return to receiving waters via wastewater effluent (i.e., septic systems). This study differentiates between total

[22] http://www.epa.gov/WaterSense/pubs/outdoor.html

rural domestic use, which includes both consumptive and non-consumptive components, and consumptive rural domestic use.

The total rural domestic per capita demands reported by USGS for 2005 range from 106 to 190 gpcd. The 2005 county rates and average for all but Humboldt and Del Norte counties are summarized in Table 4-11. Total rural domestic uses summarized here may be compared with total M&I demands provided in Tables 4-8 and 4-9 in terms of both per capita demands and mean annual total use volumes. Mean annual total rural domestic demands were computed based on the product of per capita demand and estimated population. Generally rural domestic demands are less than M&I demands, except for Trinity County where estimated rural domestic demand rates are higher than M&I. Table 4-9 also provides the estimated baseline consumptive rural domestic use for the Klamath River Basin Study.

Table 4-11. Summary of 2005 county rural domestic use

County	Annual Rural Domestic Use (AFY)	Per Capita Demand (gpcd)
Siskiyou County, California	6,621	190
Trinity County, California	1,040	158
Klamath County, Oregon	3,481	150
Modoc County, California	201	180
Total Rural Domestic Use	11,343	
Consumptive Rural Domestic Use	**4,537**	

4.2.1.4 Tribal

This discussion addresses the consumption portion of water demands associated with the six federally recognized tribes that inhabit the Klamath River Basin: The Klamath Tribes, Quartz Valley Indian Community, Karuk Tribe, Hoopa Valley Tribe, Yurok Tribe, and Resighini Rancheria. Members of these tribes live along different reaches of the Klamath River and in different areas of the basin. Table 4-12 provides a summary of the Klamath basin Native Americans by culture, recognized representative tribal government, and the general location of each tribe in the Klamath basin (taken from Table 1-1, North State Resources, Inc., 2012). The Klamath Tribes live in the Upper Klamath Basin and the other five tribes are in the Lower Klamath Basin.

Tribal Water Demands

Tribal trust resources and associated adjudicated and non-adjudicated water rights are described in this section. The needs of fish and wildlife for water are further described in Section 4.2.3.2, Environmental Resources.

Tribal water uses are unique because the associated water rights are considered trust resources.[23] Tribal domestic and industrial water uses are included in the quantification of municipal and industrial demands as well as rural domestic uses summarized above. There are also inter-relationships between tribal water demands and other non-consumptive water use categories (e.g., environmental and ceremonial uses). Critical water-related trust resources associated with instream flow needs and lake levels to support hunting, trapping, gathering, and other cultural practices are briefly described in Section 4.2.3.2, Environmental Resources. However, instream flow uses are incorporated in the Klamath River Basin Study through development of measures which are used to evaluate the impacts of climate change and implementation of adaptation strategies (refer to Chapters 5 and 6).

The federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. The tribes have reserved rights to water according to the Winters Doctrine of 1908. Additionally, the Interior Solicitor's Office stated that "Reclamation is obliged to ensure that project operations not interfere with the Tribes' senior water rights" (Interior, Office of the Solicitor, Pacific Southwest Region, 1995). And, absent a "completed adjudication or other determination of the senior water rights," projects must be "operated on the best available information" (Interior, Office of the Solicitor, Pacific Southwest and Northwest Regions, 1997). The same recognition is extended to other resources such as vegetation and wildlife.

With the exception of the Klamath Tribes, tribal water rights are not officially recognized (adjudicated) by California and Oregon. Oregon's Klamath Basin Adjudication process reached the end of its "administrative" phase in March 2013, and the OWRD reached its Final Order of Determination generally confirming the senior water rights of the Klamath Tribes. In general, tribes' water rights claims seek to assure adequate quantities of good quality water to maintain tribal trust resources including fish, instream flows, groundwater, minerals, and land as well as cultural values, which may be described as traditional religious practices, traditional food preparation, trade and barter of goods, and other practices that reinforce personal and tribal identity (North State Resources, Inc., 2012).

Table 4-12. Klamath Basin Native American peoples

Klamath Basin Native American Cultures	Recognized Representative Tribal Government	General Location of Tribe in the Klamath Basin
Yurok	Yurok Tribe Resighini Rancheria	Lower Klamath River Lower Klamath River

[23] Indian trust resources consist of certain real property, natural resources, and related rights, held in trust by the federal government for federally recognized Indian Tribes or individual Indians.

Hupa	Hoopa Valley Tribe	Lower Trinity River
Karuk	Karuk Tribe Quartz Valley Indian Community	Middle Klamath River Salmon River Scott River
Shasta (Wairuhikwaiiruka/Kammatwa)	Quartz Valley Indian Community	Scott River Shasta River Upper Middle Klamath River
Modoc	Klamath Tribes	Upper Klamath Basin
Klamath	Klamath Tribes	Upper Klamath Basin
Snake (Yahooskin)	Klamath Tribes	Upper Klamath Basin

Source: North State Resources, 2012

A portion of the adjudicated and non-adjudicated water rights of the tribes are for agricultural purposes. This consumptive use is addressed by Section 4.2.1.1, Agricultural Irrigation, which identifies the NIWR for existing crops within the basin. These demands are not differentiated between tribal and non-tribal uses.

Primary references for this and additional information related to tribal trust resources include the Klamath Facilities Removal Final Environmental Impact Statement/Environmental Impact Report (Interior and CDFG, 2012), the Trinity Mainstem Fishery Restoration Environmental Impact Statement/Environmental Impact Report (Interior et al., 2000) and the North State Resources, Inc. (2012) report, supporting the Secretarial Determination Overview Report.

4.2.1.5 Livestock
Livestock water use is included in the USGS Water Use Program estimates. However, because water use by livestock comprises only 0.2 percent of total estimated basin water use and is not likely to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

4.2.1.6 Mining and Commercial/Industrial
Mining and self-supplied commercial/industrial use is included in the USGS Water Use Program estimates. However, because this consumptive use comprises only 0.2 percent of total estimated basin water use and is not expected to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

4.2.2 Other Consumptive Uses and Losses
This section quantifies current losses associated with evaporation at the Klamath River Basin's primary lakes and reservoirs and evapotranspiration by emergent wetlands. Losses result in a reduction of water supply and are therefore included in the assessment of water supply and demand with the intent to quantify current water supply shortages.

4.2.2.1 Wetlands

This section briefly summarizes the estimation of current wetland ET used for the Klamath River Basin Study, using findings from Stannard et al. (2013). Additional work by Mayer and Thomasson (2004) was used for verification of estimated current wetland ET. Additional work by Bidlake (2002) over the more focused region of Tule Lake NWR was also reviewed in support of estimated wetland.

The Klamath River Basin Study estimates mean annual wetland ET over 341,154 acres of wetlands estimated by the National Wetland Inventory for emergent wetlands.[24] Wetland ET volume is based on work by Stannard et al. (2013), who found that during the average 190-day alfalfa-growing season wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. Estimates of average daily alfalfa and pasture ET were computed by the ET Demands model. For ET Demands model simulations, daily ET for multiple crops was computed for HUC8 sub-basins within the Klamath River Basin, similar to the approach taken by Reclamation (2014) in the West-Wide Climate Risk Assessment. Alfalfa and pasture ET computed by HUC8 sub-basin were used to estimate wetland ET. Use of the ET Demands model for these values, as opposed to alfalfa ET and pasture ET reported by Stannard et al. (2013), allows for direct comparison of the consumptive uses quantified by this study and also allows for evaluation of projected changes in wetland ET in a changing climate. Current mean annual wetland ET, based on estimates of alfalfa and pasture ET using the ET Demands modeling approach described above, is approximately 1,089,061 AFY (averaging wetland ET based on each of alfalfa ET and pasture ET). Estimates of current wetland ET by this study corroborates with the findings of both Stannard et al. (2013) and Mayer and Thomasson (2004), as shown in Table 4-13 in which current wetland ET in units of AFY were computed based on reported ET rates and the same estimated wetland area. This study's estimate of mean annual wetland ET is included in the overall estimate of current water demands provided in Table 4-4. It should be noted that the ET Demands model was not configured to include wetlands ET. However, future research involving the ET Demands model may involve determining model coefficients for wetland vegetation.

[24]http://www.fws.gov/wetlands/

Table 4-13. Comparison of average annual current wetland ET from available sources

Source of Wetland ET Estimate	Average Annual Current Wetland ET (AFY)	ET Rate (ft/yr)
Mayer and Thomasson (2004)	1,040,910	3.05
Stannard et al. (2013)	1,049,862	3.08
Klamath River Basin Study	1,089,061[25]	3.31

Mayer and Thomasson (2004) measured and modeled estimates of fall water requirements for the seasonally flooded and permanently flooded wetlands at the Lower Klamath NWR, located in the Lost River HUC8 sub-basin. They found that 60 percent of the total volume of inflow to the wetlands goes to saturate the underlying soils, adding to the water needs of seasonally flooded wetlands. Once the soils are saturated, little loss to infiltration or groundwater seepage in the wetlands would occur. Annual water requirements for both types of wetlands were comparable. Wetlands with 50 percent emergent vegetation and 50 percent open water had an estimated annual ET of 3.05 feet per year over the period 1999–2001. Using the current estimated wetland area of 341,154 acres from the National Wetlands Inventory (USFWS, 2014) for emergent wetlands in the Klamath River Basin along with the above ET rate, the estimated mean annual wetlands ET would be 1,040,910 AFY.

Stannard et al. (2013) sought to improve understanding of ET losses from wetlands by taking ET measurements using the eddy-covariance method from May 2008 through September 2010 at two sites near Upper Klamath Lake. As noted above, they estimated the area of wetlands near Upper Klamath Lake as approximately 70 square kilometers (17,300 acres). From their ET measurements, they found that during the average 190-day alfalfa-growing season, wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. In this study, Stannard et al. estimated a wetland ET rate of approximately 3.08 feet per year. If we extrapolate their computed rate for wetland ET to include the area identified in the National Wetlands Inventory (341,154 acres), their resulting estimate of mean annual wetland ET is 1,049,862 AFY.

[25] Note that the mean ET rate was computed as the mean rate across HUC8 sub-basins, while average annual current wetland ET was calculated as the ET rate multiplied by area, each unique by HUC8 sub-basin, then summed over the entire basin. The average annual current wetland ET is not mathematically equivalent to the mean ET rate multiplied by the basin's 341,154 acres of emergent wetlands. Conversely, the average annual current wetland ET computed using methods by Mayer and Thomasson (2004) and Stannard et al. (2013) was computed as the ET rate multiplied by the total basin area.

4.2.2.2 Lake and Reservoir Evaporation

The reservoirs evaluated by the study are listed in Table 4-14 along with their capacity and ownership information. Historical evaporation rates (in inches per year) and volumes (in AFY) for these reservoirs have been estimated using an energy balance model, as described below. The historical rates provide the baseline against which future estimates are compared in later sections of this chapter.

Table 4-14. Klamath River Basin primary reservoirs

Reservoir	Storage Capacity (AF)	Maximum Surface Area (acres)	Owner
Clair Engle Lake	2,448,000	17,851	Reclamation
Upper Klamath Lake	629,780	90,000	Reclamation
Clear Lake	513,330	25,760	Reclamation
Gerber Reservoir	104,460	4,000	Reclamation
Tule Lake	60,592	13,074	Reclamation
COPCO 1 Reservoir	46,867	1,000	PacifiCorp
Iron Gate Reservoir	58,794	944	PacifiCorp
John C. Boyle Reservoir	3,495	420	PacifiCorp

Source: PacifiCorp (2004c)

The estimated evaporation rates for the Reclamation reservoirs in the basin were calculated using the complementary relationship lake evaporation (CRLE) model (Morton et al., 1985). CRLE is an open water evaporation model that accounts for water temperature, albedo, emissivity, and heat storage effects to estimates of monthly evaporation. Reclamation collaborated with the DRI (Reno, Nevada) in the development and application of the model for this study.

The collaborative reservoir evaporation modeling effort with DRI was initiated as part of the WWCRA. Under the WWCRA work, Upper Klamath Lake evaporation was modeled along with 11 other reservoirs in the western U.S.

The WWCRA Water Demands Report (Reclamation, 2015) provides a detailed description of the CRLE model and its application for Upper Klamath Lake. The model parameters for Upper Klamath Lake developed under the WWCRA were directly applied for simulation of open water evaporation in Upper Klamath Lake in this study. The other reservoirs listed in Table 4-14 were also modeled using the same approach.

The CRLE model calculates estimated evaporation for historical average reservoir conditions. Average monthly historical reservoir conditions (storage volume and surface area) were calculated using historical data and assumed constant for the analysis period (1950–1999). The same air temperature-based relationship used for estimating solar radiation for Upper Klamath Lake, based on Klamath Falls

Agrimet weather station data, was applied for modeling evaporation at the other reservoirs. Relationships for estimation of dewpoint depression (humidity) were developed based on historical data from the weather stations, discussed above in Section 4.2.1.1, Agricultural Irrigation, and as shown in Figure 4-2.

Table 4-15 includes a summary of the CRLE model results for the historical baseline period (1950–1999), including average annual evaporation rates and net evaporation (evaporation minus precipitation) rates for each reservoir. Table 4-15 also includes evaporation and net evaporation volume estimates based on the model results and historical average reservoir conditions. Note that historical average reservoir conditions differ from the maximum conditions reported in Table 4-14.

Table 4-15. Klamath River Basin reservoirs evaporation model results summary for 1950 to 1999 historical baseline period

Reservoir	Evaporation (inches/year)	Evaporation (AFY)[26]	Net Evaporation (inches/year)	Net Evaporation (AFY)[11]
Clair Engle Lake	45.0	49,152	-26.0	-28,412
Upper Klamath Lake	44.0	263,483	21.1	125,977
Clear Lake	45.6	81,711	32.0	57,300
Gerber Reservoir	44.4	8,947	24.1	4,862
Tule Lake	45.2	23,723	33.3	17,484
COPCO 1 Reservoir	43.9	3,427	20.8	1,626
Iron Gate Reservoir	44.8	3,446	27.2	2,089
J.C. Boyle Reservoir	44.2	729	22.5	371

Stannard et al. (2013) conducted an open water and wetland evaporation study for Upper Klamath Lake, Oregon. Bowen ratio energy balance was utilized to estimate open water evaporation during the summer and fall of 2008 and the growing seasons of 2009 and 2010. To evaluate the skill of CRLE application in the Klamath River Basin, the CRLE model was forced with measured solar radiation, air temperature, and dewpoint temperature obtained from the Klamath Falls Agrimet station for the 2008–2010 study period of Stannard et al. (2013). Results of the seasonal comparison are favorable, with daily average evaporation rates for this study of 0.20 inches per day compared to 0.21 inches per day by Stannard et al. (2013).

[26] Reservoir evaporation and net evaporation volumes were computed using mean monthly surface area over the simulation period.[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

Deleted: ¶

4.2.2.3 Operational Inefficiencies

Operational inefficiencies such as canal seepage and on-farm losses associated with irrigation methods are not explicitly quantified in the Klamath River Basin Study. The largest irrigated region in the watershed is Reclamation's Klamath Project. Within the Project area, on-farm runoff and canal spills are captured in drains and reused such that the overall efficiency of the Project is considered to be relatively high. This is based on water budgets developed as part of previous studies (Davids, 1998; Freeman and Burt, undated; Reclamation, 2007b). For other irrigated regions, such as the Shasta and Scott Valleys, this study assumes that non-beneficial consumptive use of conveyance and on-farm losses is not a significant portion of the overall losses in the watershed. The USGS Water Use Program estimates for agricultural irrigation use include crop demands, conveyance losses, and on-farm losses.

4.2.2.4 Phreatophyte Vegetation

Phreatophytes are defined as deep-rooted plants that obtain water from the water table or in the vadose zone just above the water table. Phreatophyte losses are included in the water budget through the natural flow computations (refer to Chapter 3) and therefore are not shown separately as losses. Needs of other vegetation for water are also included in the water budget. For example, BLM and USFS conservation initiatives associated with the 1994 Northwest Forest Plan preserve old growth vegetation and riparian buffers throughout the Southern Oregon / Northern California Coast Evolutionary Significant Unit and range of the Northern Spotted Owl (BLM and USFS, 2005).

> **Non-Consumptive Uses**
>
> Non-consumptive uses include recreation, environmental resources, hydropower, and aquaculture. Because non-consumptive uses do not result in a reduction of available water supply, they are addressed in Chapter 5, System Reliability as measures for evaluating the impacts of climate change and implementation of adaptation strategies.

4.2.3 Non-Consumptive Uses

Non-consumptive uses are those which do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.), water needs to support fish and wildlife, and hydropower production, among others. In one sense, these uses may be considered demands in that certain water levels or flows are required to support them. However, because these uses do not result in a loss of water in a planning context, the Klamath River Basin Study addresses them in terms of measures of system reliability. The measures are used to evaluate how well the available water supply is able to meet various needs in the watershed.

This section briefly describes the identified non-consumptive uses in the Klamath River Basin. However, details of water requirements and/or needs to sustain these uses are further quantified in Chapter 5, System Risk and Reliability Analysis.

4.2.3.1 Recreation

The expansive rural landscape of the Klamath River Basin offers a myriad of outdoor recreational opportunities, many of which are either directly or indirectly associated with the basin's water resources. Rivers, streams, and lakes are common throughout the basin's mountainous landscape, and reservoirs and wetlands exist in the valleys and high plateau areas of the central and eastern portions of the basin. The basin's rivers, streams, lakes, reservoirs, and wetlands provide a variety of recreational opportunities including camping, sightseeing, hunting, fishing, boating, hiking, and wildlife viewing.

There are five national forests within the basin (Klamath, Fremont, Winema, Six Rivers, and Modoc), a joint national and State park (Redwood), a national park (Crater Lake), two national monuments (Lava Beds and Cascade-Siskiyou) and five national wildlife refuges that make up the Klamath Basin NWR Complex (Klamath Marsh, Tule Lake, Clear Lake, Upper Klamath, and Lower Klamath). Recreation opportunities in these forests, parks, and refuges include camping, hiking, snowmobiling, sightseeing, wildlife viewing, hunting, and fishing.

Large sections of the Klamath River and its tributaries are designated as national wild and scenic rivers (WSR) under the Wild and Scenic Rivers Act, including segments of the Klamath, Scott, and Salmon Rivers and Wooley Creek totaling 297 miles. Extensive public and private recreational opportunities exist along the Klamath River and its tributaries.

The Klamath River Basin Study focuses on flow-related recreational uses, as they are more directly associated with water supply than other recreational demands such as camping and sightseeing, for example. The recreational uses considered in this study are fishing and boating in the Klamath and Trinity Rivers. Chapter 5, System Reliability quantifies optimal flow ranges for these activities, as reported by the Klamath Facilities Removal EIS/EIR (Interior and CDFG, 2012).

The modeling framework of the Klamath River Basin Study does not allow for evaluation of impacts of climate change on natural unmanaged lakes within the watershed; however, evaluation of reservoir levels is part of the system reliability analysis in Chapter 5.

4.2.3.2 Environmental Resources

Numerous fish species use the Klamath Basin during all or some portion of their lives. Native species include salmonids, lamprey, sturgeon, suckers, minnows, and sculpin. Many other species are present in the Klamath River estuary. Salmonids in the Klamath River include fall and spring Chinook salmon; coho salmon; fall-, winter-, and summer-run steelhead; and coastal cutthroat trout. The salmonids share many similar life-history traits, but the timing of their upstream

migrations, habitat preferences, and distributions differ (Interior and CDFG, 2012). A number of non-native species have also been introduced into the watershed including yellow perch, largemouth bass, spotted bass, sunfish, and catfish. These species all have unique needs for Klamath River water which must be considered in conjunction with management practices for human uses.

Water Quality

Water quality in the Klamath River Basin is affected by both natural and human influences. The volcanic terrain supports soils that are naturally high in phosphorus. Human influences including development, wetland draining, agriculture, ranching, logging, and water management have altered streamflows and water temperatures and increased nutrient and sediment loading in the river system. In addition, mining activities, dam construction, and management for hydropower in the Lower Klamath Basin have further affected river conditions (Interior and CDFG, 2012). As a result of natural and human activities, water quality standards in the Upper Klamath Basin have not been met for many years (Stillwater Sciences, 2013). Table 4-16 summarizes the water quality impaired water bodies in the Klamath River Basin as identified by the Klamath Facilities Removal EIS/EIR (Table 3.2-8 in Interior and CDFG, 2012). The identified water quality impairments impact the beneficial uses of the Klamath River designated by the Klamath Facilities Removal EIS/EIR, which are categorized as Aesthetic and Cultural, Agricultural Water Supply, Commercial, Fish and Wildlife, Potable Water Supply, Industrial Water Supply, and Navigation.[27] For example, known and/or perceived concerns over health risks associated with seasonal algal toxins have resulted in the alteration of traditional cultural tribal practices such as gathering and preparation of basket materials and plants, fishing, ceremonial bathing, and ingestion of river water.

[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

Table 4-16. Water quality impaired water bodies within the area of analysis[1]

Water Body Name	Water Temperature	Sedimentation	pH	Organic Enrichment/Low Dissolved Oxygen	Nutrients	Ammonia	Chlorophyll-a	Microcystin
Oregon[2]								
Sprague River and tributaries	X^{S}		X^{S}	X^{S}				
Williamson River and tributaries	X							
Upper Klamath Lake and Agency Lake			X	X			X	
Upper Klamath River (Keno Dam to Link River Dam, including Keno Impoundment/Lake Ewauna)			X^{S}	$X^{SP,S,F,W\ (3)}$		$X^{SP,S,F,W}$	X^{S}	
Upper Klamath River Oregon-California state line to Keno Dam (including J.C. Boyle Reservoir) (4)	$X^{SP,S,F,S\ (5)}$			$X^{SP,S,F,W\ (3)}$				
California								
Lower Lost River (Tule Lake, Lower Klamath Lake National Wildlife Refuge, and Mt. Dome)			X		X			
Middle Klamath River Oregon-California state line to Iron Gate Dam (including COPCO Lake Reservoir [1 and 2] and Iron Gate Reservoir)	X			X				X
Middle Klamath River Iron Gate Dam to Scott River Reach 6	X			X	X			X
Shasta River	X			X				
Scott River	X	X						
Salmon River	X							
Middle and Lower Klamath River Scott River to Trinity River Reach 7	X			X	X			X
Lower Klamath River-Trinity River to Mouth	X	X		X	X			

Source: Table 3.2-8 in Interior and CDFG, 2012

Notes:

1 While there are additional water quality impaired waterbodies in the area of analysis, the waterbodies listed in this table are the ones that are directly relevant to the water quality analysis for this Klamath Facilities Removal EIS/EIR.

2 Oregon lists specific reaches of the Klamath River by river mile and includes specific seasons, in some cases (Kirk et al., 2010).

3 Listed for dissolved oxygen only (non-spawning) (Kirk et al., 2010).

4 Oregon defines particular river miles for their listings.

5 Non-spawning (Kirk et al., 2010).

6 Selected minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include Beaver Creek, Cow Creek, Deer Creek, Hungry Creek, and West Fork Beaver Creek (USEPA, 2010a).

7 Minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include China Creek, Fort Goff Creek, Grider Creek, Portuguese Creek, Thompson Creek, and Walker Creek (USEPA, 2010a).

Key:

Sp = Listed for spring season
S = Listed for summer season
F = Listed for fall season
W = Listed for winter season

Effects on regional water quality have resulted in multiple federal, state, and tribal programs and planning documents to regulate and protect water quality in the area of the Klamath River Basin. For example, the states of Oregon and California have established and obtained EPA approval of water quality standards (referred to as "water quality objectives" in California) for waters in the Klamath River Basin, including designated beneficial uses (PacifiCorp, 2004b; Interior and CDFG, 2012). Also, several of the Klamath River Basin native tribes have adopted their own water quality objectives for portions of the Klamath and Trinity Rivers. Water quality objectives adopted by the Hoopa Valley Tribe establish water quality objectives for those portions of the Trinity and Klamath Rivers under the jurisdiction of the tribe. The Yurok and Karuk Tribes have also adopted water quality objectives, as has the Resighini Rancheria; however, the associated water quality plans have not yet been approved by USEPA (NCRWQCB, 2010b).

For water bodies included on the Clean Water Act Section 303(d) list of impaired water bodies, the state with jurisdiction over the water body must develop TMDLs to protect and restore beneficial uses of water. TMDLs set limits on the amount of pollutants that can be added to a water body while still protecting identified beneficial uses. TMDLs have been established for various parts of the Klamath River Basin since about 2001. The status and pollutants regulated under Klamath River Basin TMDLs are summarized in Table 3.2-9 of the Klamath Facilities Removal Final EIS/EIR (Interior and CDFG, 2012).

Water levels and flow rates are inherently related to water quality in the Klamath River Basin. The need for improved water quality by environmental resources may be considered a demand, in one sense, because threshold flows are needed to sustain a healthy river system. However, because these needs are non-consumptive, the Klamath River Basin Study incorporates water quality criteria and associated TMDLs in the analysis of system reliability. Specifically, environmental health of the watershed is assessed through analysis of water temperature as a surrogate for overall watershed ecological health. Water quality criteria and TMDLs for stream temperature are incorporated as measures for evaluation of system reliability in Chapter 5.

Instream Flow Targets

Instream flow targets have been established for parts of the Klamath River Basin both through state codes, state and federal regulatory requirements, and cooperative agreements such as Reclamation's 2013 Biological Assessment for Proposed Klamath Project Operations and the associated 2013 non-jeopardy [28] Biological Opinion issued by the NMFS and USFWS. Instream flow targets are one means of working toward the maintenance and even recovery of threatened and endangered species in the basin. However, recommended instream flows are highly uncertain due to limited data availability and our limited understanding of

[28] An ESA Section 7 non-jeopardy Biological Opinion is one where USFWS or NMRS determines that a federal action is not likely to jeopardize the existence of a listed species or result in the destruction or adverse modification of critical habitat.

all of the direct and indirect effects of the environment on the species it supports. As we learn more about species recovery in responses to instream flow actions, these recommendations are likely to evolve through time.

Instream flow recommendations exist for reaches of the Klamath River (Reclamation, 2012d; NMFS and USFWS, 2013; Interior and CDFG, 2012; Hardy et al., 2006) as well as the tributaries of the Shasta River (McBain and Trush, 2014) and Trinity River (Interior, 2000). In addition, the federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. Interior supports Winters Doctrine rights which entitle tribes in the Klamath River Basin to sufficient water to support fishing and harvesting and cultural practices. Also, recognition of tribal reserved fishing rights is consistent with the federal precedent set in United States v. Adair (Interior and CDFG, 2012). Although the Klamath River Basin tribes have reserved rights to support their livelihoods, for the most part instream flow needs to support those activities have not been quantified, with the exception of the Klamath Tribes as part of Oregon's Klamath Basin adjudication process.

Similar to other non-consumptive water uses, recommended instream flow targets may be considered a demand in that certain flows are required to sustain fish species and support other uses. However, since these uses do not result in a reduction of water supply, they are incorporated in the analysis of system reliability in Chapter 5. Namely, instream flow targets may be used as measures in the evaluation of impacts of climate change on the watershed with and without implemented adaptation strategies. Details of recommended instream flow targets are included in Chapter 5.

Wildlife Refuge Water Targets

Klamath Basin National Wildlife Refuges is a complex of six refuges: Lower Klamath, Tule Lake, and Clear Lake in northern California and Bear Valley, Upper Klamath, and Klamath Forest Refuges in southern Oregon. All of the complex refuges are adjacent to or within Reclamation's Klamath Project with the exception of Bear Valley, which was established in 1978 and consists of old growth pine forest to protect a major night roost site for wintering bald eagles in Southern Oregon. The USFWS manages the refuges under the Migratory Bird Treaty Act (codified as 16 U.S.C. §§ 703-712), National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. §§ 668dd-668ee), National Wildlife Refuge System Improvement Act (Pub. L. 105-57, 111 Stat. 1252-1260), and other laws pertaining to the NWR System (Reclamation, 2012d). They were established by various executive orders starting in 1908, and support many fish and wildlife species and provide suitable habitat and resources for migratory birds of the Pacific Flyway. Each year these refuges serve as an annual stopover for approximately three-quarters of the flyway waterfowl with peak concentrations of over one million birds. Reclamation manages leases on refuge lands for agricultural purposes through a cooperative agreement with the USFWS (Reclamation, 2012d).

The refuges (with the exception of Bear Valley and Clear Lake) have federally-reserved water right claims for the water necessary to satisfy the refuges' primary purposes subject to more senior water rights in the basin, including the Klamath Tribes and Reclamation's Klamath Project. The 2013 BA for Klamath Project operations outlines the availability of water to the Lower Klamath and Tule Lake NWRs (Reclamation, 2012d). In addition, Risley and Gannett (2006) estimated water needs of the Lower Klamath and Tule Lake NWRs using evapotranspiration estimates, with different rates for each of four land-use categories. With the exception of open water evaporation and wetland ET, water used by refuges is generally non-consumptive. Recommended targets, like those summarized by the above sources, are provided in Chapter 5, System Reliability and incorporated as measures for evaluation of system reliability.

4.2.3.3 Hydropower

The Klamath River Basin has nine major hydropower generating facilities, seven in the Upper Klamath Basin and two in the Trinity River sub-basin. Other small hydropower generating facilities in the basin include the C Drop Plant on Reclamation's Klamath Project and two small hydropower facilities in Siskiyou County. The seven major hydropower plants in the Upper Klamath Basin are owned and operated by PacifiCorp of Portland, Oregon. The PacifiCorp facilities are regulated by the Federal Energy Regulatory Commission (FERC) as Project No. 2082 and are operating under annual licenses since the expiration of the original license in March 2006. Future operations are dependent on the resolution of the relicensing proceedings for these facilities, which may be addressed through either issuance of a new project license by FERC or the passage of federal legislation enacting the Klamath Hydroelectric Settlement Agreement (KHSA) and related Klamath settlements, which provide for the potential removal of these facilities.

Since 1992, operations of PacifiCorp's facilities have been adjusted to protect ESA-listed threatened species. These adjustments were made to address then-current minimum levels in Upper Klamath Lake and minimum instream flows in the Link River and in the Klamath River below Iron Gate dam described in biological opinions for Reclamation's Klamath Project (PacifiCorp, 2004b). The current river flow and Upper Klamath Lake level requirements are described in the 2013 Joint Biological Opinion for Klamath Project Operations by the USFWS and NMFS (NMFS and USFWS, 2013). If PacifiCorp's hydroelectric dams are removed as part of the KBRA/KHSA, the hydroelectric water rights at all of PacifiCorp's Klamath facilities (except Fall Creek) in Oregon will be dedicated or assigned to instream water rights and administered by the ODFW, while those in California will be abandoned, according to Section 7.6.5 of the KHSA.

The other two major hydropower generating facilities are located in the Trinity River sub-basin. The Lewiston powerplant provides power to the adjacent Trinity River Fish Hatchery and additional energy is sold. Trinity Power plant is a peaking plant associated with the Trinity River Diversion for Reclamation's Central Valley Project. Flow rates and associated power production at both

facilities are subject to the Trinity River Restoration Program Record of Decision (Interior, 2000).

The Klamath River Basin Study provides the basis for evaluations of changes in future hydrologic conditions and resulting changes in power generation capacity and timing. The analysis of system reliability (refer to Chapter 5) allows for quantification of projected turbine releases and hydropower production as a result of climate change and implemented adaptation strategies. This study does not evaluate projected changes in the demand for hydropower in a changing climate. Water rights and instream flow requirements associated with hydropower production are utilized in the system reliability analysis as measures for evaluation of changes in power production associated with various managed flow conditions in a changing climate.

4.2.3.4 Aquaculture

Another non-consumptive use of water within the Klamath River Basin includes aquaculture, which is defined as the rearing of aquatic animals. This use is quantified by the USGS Water Use Program; however, the percentage of total basin water use is only 3 percent. Due to the small percentage of overall water use, the fact that this use is largely non-consumptive, and the lack of information as to the impacts of climate change on aquaculture, this use is not further considered in the Klamath River Basin Study.

4.3 Effects of Climate Variability and Change on Demand

4.3.1 Climate Change Scenarios

The Klamath River Basin Study primarily utilizes climate change scenarios that are derived using an ensemble informed hybrid delta (HDe) method approach (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d). The scenarios are derived from both CMIP3 and CMIP5 bias corrected and spatially downscaled (BCSD) GCM climate projections, as these are considered equally likely potential climate futures at this time. The approach allows a high number of CMIP3 and CMIP5 climate projections to be distilled into a small number of representative climate change scenarios. The same scenarios used for evaluation of future water supply are used in this chapter's estimation of demands to meet consumptive uses, namely M&I and rural domestic as well as losses due to reservoir evaporation. Development of future agricultural scenarios involved using similar climate change scenarios, but with prior adjustments made to the underlying BCSD climate projections to account for biases in projected versus observed weather over irrigated areas (for more information, refer to WWCRA Demands Assessment, Reclamation, 2015).

Development of climate change scenarios is described in Section 3.5.1.2, Deriving Climate Change Scenarios from Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in

this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). Five scenario types are derived from the large number of CMIP3 and CMIP5 BCSD climate projections: warm-wet (WW), warm-dry (WD), central-tendency (CT), hot-wet (HW), and hot-dry (HD). Discussions of how the temperature and precipitation projections for the five HDe scenarios are used to estimate the various future demands are provided in the following sections.

4.3.2 Growth Scenarios

Future water demand with respect to consumptive uses and evaporation losses may have a number of driving forces aside from those directly related to climate, including demographics, land use, technological development, and socioeconomics. Because it is highly uncertain how these driving forces may unfold in the future, we employ a scenario-based approach to projected growth.

To evaluate the impacts of climate change on system performance of existing and anticipated water infrastructure and operations in the Klamath River Basin, a baseline condition is established. In typical long term planning studies, this baseline condition may be called the Future No Action alternative. A Future No Action alternative incorporates climate change scenarios and requires that assumptions be made regarding future growth in the watershed. The Future No Action alternative in the Klamath River Basin Study corresponds with one future growth scenario and ten climate change scenarios (five CMIP3-based scenarios and five CMIP5-based scenarios), each for the 2030s and 2070s, for a total of twenty future scenarios.

In general, the growth scenario encompasses projected population growth, where reported by the states and municipalities, and current agricultural practices. A brief description of the growth scenario is provided in this section. Assumptions regarding the future growth scenario are summarized below and in Table 4-17. Additional details regarding the growth scenario are provided in Section 4.3.3 which quantify the impacts of climate change on water demands.

As shown in Table 4-17, this study assumes that cropping patterns and number of irrigated acres are static in quantifying future agricultural irrigation demands. Altered cropping patterns may be considered in this study as implemented adaptation strategies in the analysis of system reliability. For M&I and rural domestic uses, a defined percentage of the water use is landscape irrigation and this is also considered static. Population estimates that define the total M&I and rural domestic future water usage are based on two primary sources. If population projections are provided by individual municipal water plans, those projections are incorporated into the demand scenario. For regions where municipal water plans may not exist, and for rural domestic water use, historical population trends are extrapolated into the future and incorporated in the demand scenario. For losses due to reservoir or lake evaporation, it is assumed that historical average reservoir levels exist in the future. Alternative future reservoir levels are considered as implemented adaptation strategies in the analysis of system reliability. Finally, for future wetland ET estimates, it is assumed that the current

number of wetland acres (based on the current National Wetland Inventory) is static.

Table 4-17. Summary of assumptions for Klamath River Basin Study future growth scenario

Consumptive Use or Loss	Element	Assumptions for Future Scenarios
Agricultural irrigation		
	Cropping patterns	Static, based on historical
	Irrigated acres	Static, based on historical
M&I and rural domestic	Landscape irrigation = 40 percent of total use	Static, based on historical
	Population growth	Based on water plans or extrapolations of historical trends (if projections not available)
Lake and reservoir evaporation	Average lake and reservoir levels	Static, based on historical
Wetlands ET	Wetland acres	Static, based on historical

4.3.3 Projected Future Water Demands

Numerous factors were considered in the estimation of the basin's future water demands. The primary factors include population growth, agricultural practices, and climate change. Population growth, agricultural practices, and other socioeconomic conditions are incorporated in the demand scenario described above. Projections of climate change are incorporated separately, such that there are five HDe climate scenarios for each of the CMIP3- and CMIP5-based projections and for each future time horizon (2030s and 2070s). Each of these climate change scenarios is paired with the single demand scenario considered in this study.

As discussed previously, rigorous quantitative analyses were performed to estimate the demands to meet predominant consumptive uses in the watershed: agricultural irrigation, M&I, rural domestic, wetlands, and losses due to reservoir evaporation. The implications of climate change on non-consumptive uses are evaluated as part of Chapter 5, System Reliability Analysis.

Table 4-18 summarizes the projected changes in basin-wide consumptive use (both human influenced and natural) for the predominant use categories: agricultural irrigation, M&I, rural domestic, and losses due to reservoir evaporation and wetland ET. Projected changes are presented for all five HDe climate change scenarios for each of the CMIP3- and CMIP5-based projections, as well as for two future time horizons, the 2030s and 2070s.

Table 4-18. Summary of basin-wide projected changes in consumptive water use and losses

Scenario	Period	BCSD Projection	Total (AFY)	Total Percent Change
Historical	Historical	-	2,039,430	-
Warm Dry	2030	CMIP-3	2,233,781	10%
Warm Dry	2030	CMIP-5	2,277,042	12%
Warm Wet	2030	CMIP-3	2,190,454	7%
Warm Wet	2030	CMIP-5	2,225,238	9%
Hot Dry	2030	CMIP-3	2,387,983	17%
Hot Dry	2030	CMIP-5	2,405,865	18%
Hot Wet	2030	CMIP-3	2,313,274	13%
Hot Wet	2030	CMIP-5	2,349,212	15%
Central Tendency	2030	CMIP-3	2,284,936	12%
Central Tendency	2030	CMIP-5	2,304,374	13%
Warm Dry	2070	CMIP-3	2,380,969	17%
Warm Dry	2070	CMIP-5	2,324,159	14%
Warm Wet	2070	CMIP-3	2,308,778	13%
Warm Wet	2070	CMIP-5	2,266,970	11%
Hot Dry	2070	CMIP-3	2,528,603	24%
Hot Dry	2070	CMIP-5	2,568,869	26%
Hot Wet	2070	CMIP-3	2,428,364	19%
Hot Wet	2070	CMIP-5	2,501,320	23%
Central Tendency	2070	CMIP-3	2,393,777	17%
Central Tendency	2070	CMIP-5	2,406,350	18%

Similarly, for all future climate scenarios Figure 4-5 summarizes projected changes for each type of consumptive use or loss considered in the Klamath River Basin Study for the 2030s and 2070s.

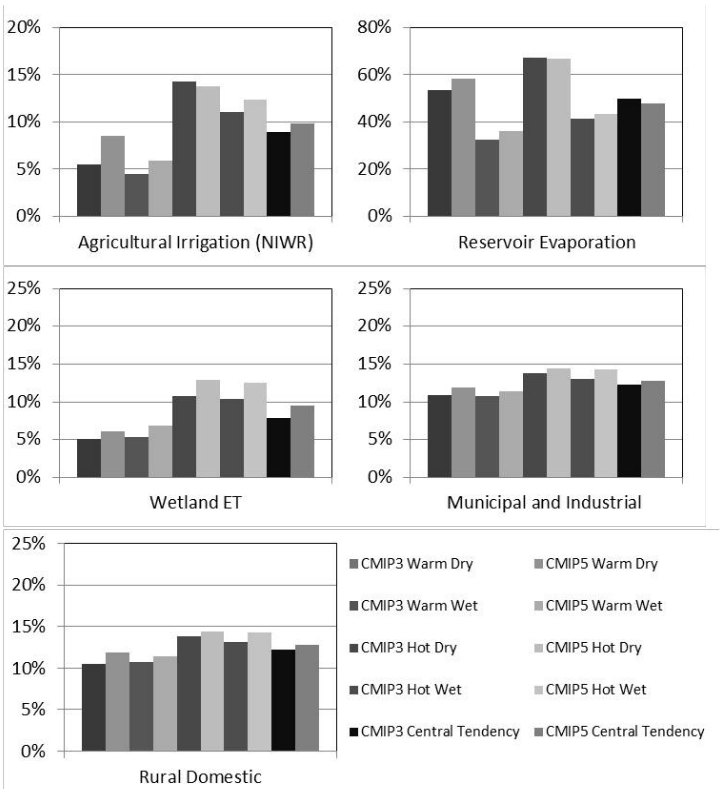

Figure 4-5. Summary of basin-wide projected changes in consumptive water use and losses for the 2030s by use type

4.3.3.1 Human Influenced Consumptive Uses

Projected consumptive uses to meet future demands are summarized in this section, incorporating projected HDe climate scenarios for two future time horizons, the 2030s and the 2070s, and a single future growth scenario. Descriptions of the approaches used to incorporate climate change scenarios and growth scenarios are provided in the respective subsections below on various consumptive uses and losses.

Agricultural Irrigation

To evaluate the impacts of climate change on agricultural irrigation demands, the ET Demands model described in Section 4.2, Current Demand was implemented using the approach described in Reclamation (2015). Any differences in the approach details are discussed below.

For example, the Klamath River Basin Study utilizes two future time periods for analysis of climate change impacts (2030s and 2070s), compared with three future time periods (2020s, 2050s, 2080s) used in the WWCRA. Also, there are slight differences in the projection ensemble selection process for development of HDe scenarios. This study utilizes a subset of 10 climate projections to inform each of the five climate scenarios, while the WWCRA utilizes the full set of climate projections. Further discussion of the approach for climate change scenario development for this study is provided in Chapter 3. Another difference in approach for assessing agricultural irrigation demands is the use of both CMIP3 and CMIP5 projections in this study; the WWCRA uses solely CMIP3 projections. At the time the WWCRA work began, CMIP5 projections were not readily available.

As mentioned above, a single growth scenario was used in conjunction with multiple future climate scenarios to encompass a range of potential future consumptive water demands. Collectively these scenarios comprise the Future No Action scenario. This alternative generally includes historical cropping patterns and irrigated acreage. Additional approach details for assessment of future agricultural irrigation demands are provided in this section. In the discussion of Current Water Demands, the ET Demands model is described as using basal crop coefficient (K_{cb}) curves, which are developed as a function of GDD. For this study, the K_{cb} curves for annual crops are developed using baseline (historical) temperatures, while perennial K_{cb} curves are developed using future projected temperatures.

Changes in future farming practice of annual crops, such as potential earlier planting, development, and harvest, are uncertain under warming climatic conditions. These potential changes will depend on future crop cultivars, water availability, and economics. For these reasons, static phenology K_{cb} curves were simulated for future periods where historical baseline temperatures were used for simulating planting, crop development, and harvest dates using the GDD approach previously described. In effect, all scenarios and time periods have identical seasonal K_{cb} curve shapes for each annual crop, and only exhibit differences in daily ET_c magnitudes due to daily ET_o and precipitation differences. A detailed discussion on this static phenology approach is included in Reclamation (2015).

The future irrigation demands results cover mean annual precipitation, temperature, reference evapotranspiration (ET_o), crop evapotranspiration (ET_c), and net irrigation water requirement (NIWR, both depth and volume). Mean monthly values of perennial crop ET_c for future time periods and scenarios are also presented to highlight potential changes in seasonal ET_c.

The future ET_o, ET_c and NIWR subbasin and basin total estimates were calculated using the same methods as the historical baseline values. Specifically, the NIWR and ET_c rates for each crop within a given HUC8 subbasin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 subbasin,

and all crop values are summed to calculate weighted average HUC8 subbasin NIWR and ET_c rates. ET_o, ET_c and NIWR estimates for the entire basin were calculated using the ratios of subbasin to basin irrigated acres.

The results are summarized in a series of figures and tables (similar in format to the WWCRA [Reclamation, 2015]), with appended detailed results and additional figures. The figures below show projected changes in temperature, precipitation, ET_o, ET_c, and NIWR for the CMIP5-based climate scenarios and both future time periods (2030s and 2070s). CMIP3-based figures are shown in Appendix C. Projected changes are presented as the difference from historical baseline averages for temperature, and percent change from baseline averages for all other variables. Projected absolute values of ET_o, ET_c, and NIWR for the different scenarios and time periods are also included in Appendix C.

Figure 4-6 illustrates the spatial distribution of projected precipitation percent change for the different scenarios and time periods. Depending on the scenario, basin average precipitation percent changes range from -7.4 percent to +20.8 percent for the 2070 time period (considering CMIP5-based scenarios), with the central tendency scenario showing a general increase throughout the basin.

Figure 4-7 shows the spatial distribution of projected mean temperature change for the different climate scenarios and time periods. Increased temperatures are shown for all scenarios and periods. with slightly larger projected mean temperature changes in the northeast portion of the basin for all scenarios. Depending on the scenario, basin average temperature changes range from 1.6 to 8.4 degrees F for the 2070s time period (considering CMIP5-based scenarios).

Figure 4-8 shows the spatial distribution of projected ET_o percent change for different climate scenarios and time periods, and Table 4-19 provides a comparison of projected changes in annual ET_o for the central tendency climate scenario. Similar to temperature, the projected percent change in ET_o is larger in the northeast portions of the basin.

Figure 4-9 illustrates the spatial distribution of projected ET_c percent change for different climate scenarios and future periods, and Table 4-20 provides a comparison of projected changes in annual ET_c for the central tendency climate scenario. Spatial differences in the distribution of projected percent change in ET_c are largely due to differences in crop type and historical baseline ET_c. The northeast portion of the basin is projected to experience the largest percent change increase for all projected time periods, largely due to the fact that the difference between the projected and historical baseline ET_c is fairly large relative to the baseline estimate of ET_c (see Figure 4-4). The predominant crops in the Upper Klamath Basin include alfalfa, pasture grass, other hay, and winter wheat. In the Lower Klamath Basin, where alfalfa, other hay, and spring wheat are the dominant crops, projected increases in ET_c are lower. The Lower Klamath HUC8 subbasin has a projected decrease in ET_c, despite projected climate warming in all

HUC8 subbasins. The increase may be due to projected changes in the harvesting of grass hay, which is projected to occur earlier in the year.

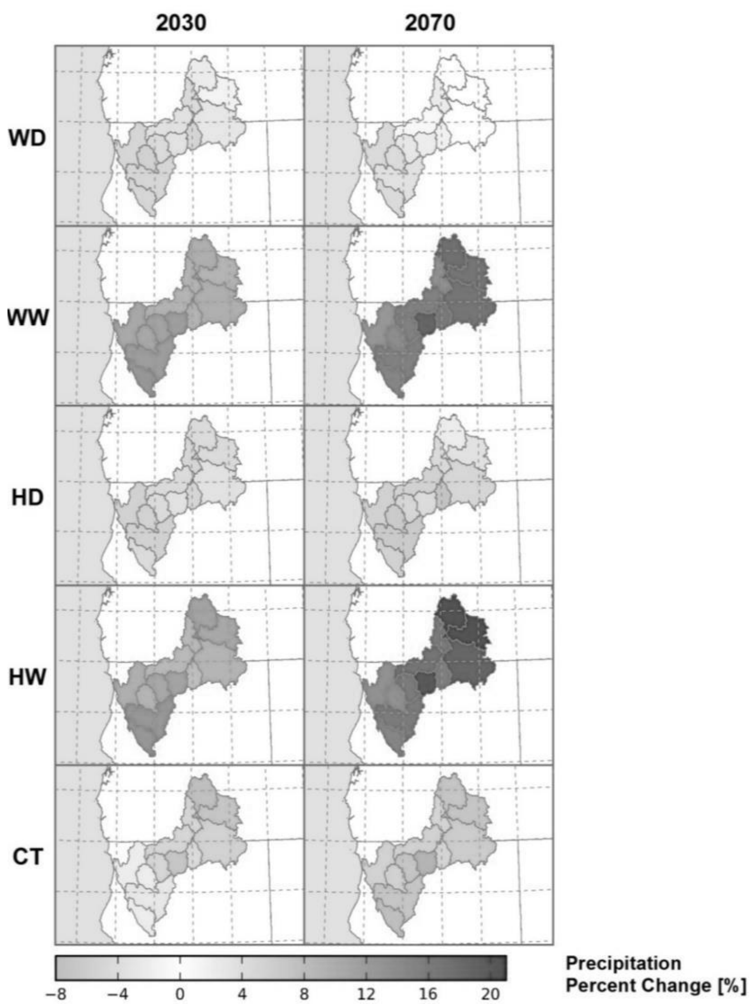

Figure 4-6. Klamath River Basin - Spatial distribution of projected precipitation change for different climate scenarios and time periods (CMIP5 climate scenarios)

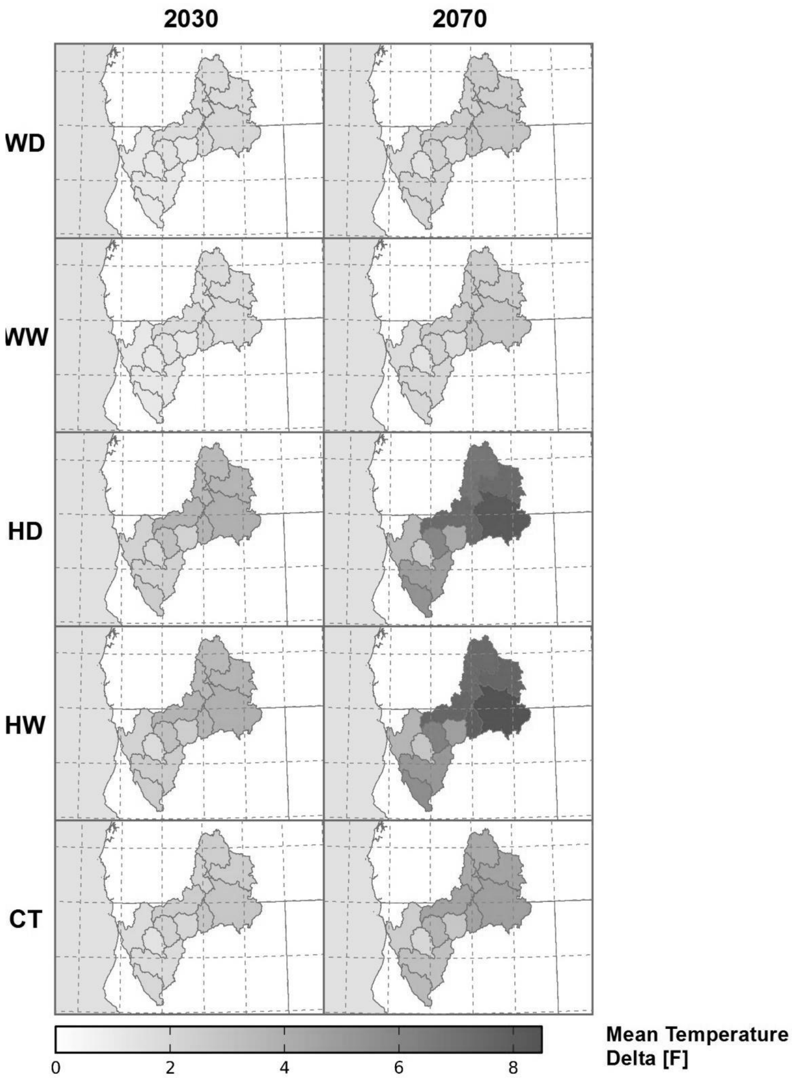

Figure 4-7. Klamath River Basin - Spatial distribution of projected temperature change for different climate scenarios and time periods (CMIP5 climate scenarios)

17-01174_013609;17-01174_013609;17-01174_013610;17-01174_013611;17-01174_013612;17-01174_013613;1...

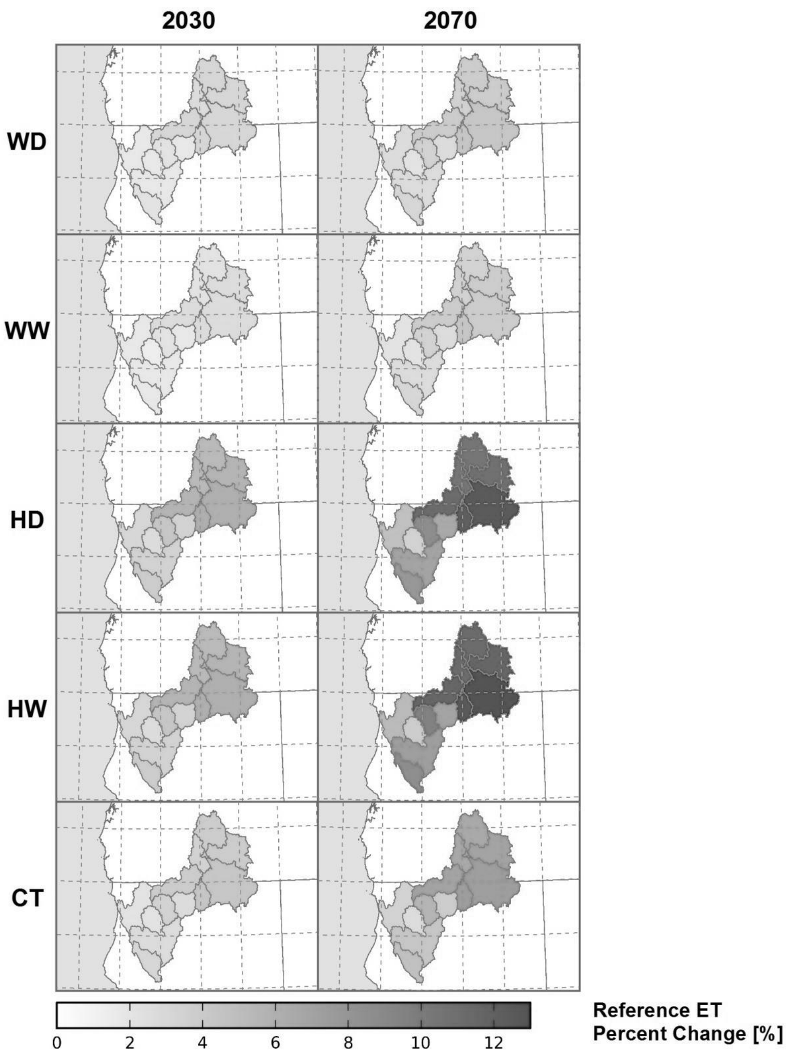

Figure 4-8. Klamath River Basin - Spatial distribution of projected reference evapotranspiration percent change for different climate scenarios and time periods (CMIP5 climate scenarios)

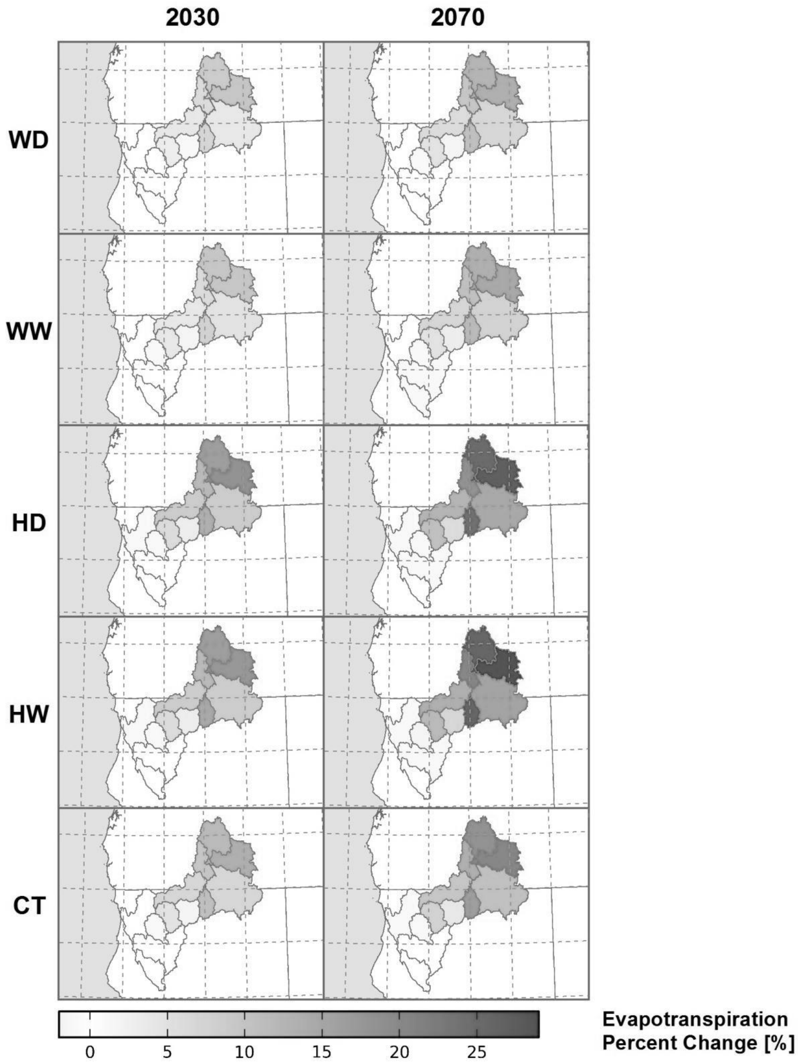

Figure 4-9. Klamath River Basin - Spatial distribution of projected crop evapotranspiration percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios).

Table 4-19. Comparison of projected changes in annual reference evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	3.3%	3.8%	5.9%	6.43%
HUC_18010202	Sprague	3.4%	4.0%	6.1%	6.7%
HUC_18010203	Upper Klamath Lake	3.2%	3.7%	5.7%	6.3%
HUC_18010204	Lost	3.6%	4.3%	6.7%	7.4%
HUC_18010205	Butte	3.7%	4.4%	6.6%	7.4%
HUC_18010206	Upper Klamath	3.5%	4.1%	6.1%	6.8%
HUC_18010207	Shasta	2.3%	2.7%	3.7%	4.2%
HUC_18010208	Scott	2.8%	3.4%	4.9%	5.5%
HUC_18010209	Lower Klamath	2.1%	2.4%	3.2%	3.4%
HUC_18010210	Salmon	2.0%	2.3%	2.8%	2.9%
HUC_18010211	Trinity	2.3%	2.7%	3.9%	4.3%
HUC_18010212	South Fork Trinity	2.5%	3.0%	4.4%	4.8%
Total Basin		3.4%	3.9%	6.0%	6.7%

Table 4-20. Comparison of projected changes in annual crop evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins.

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	10.0%	11.9%	16.6%	18.3%
HUC_18010202	Sprague	11.6%	13.8%	18.54%	20.4%
HUC_18010203	Upper Klamath Lake	6.9%	9.9%	12.8%	14.0%
HUC_18010204	Lost	5.7%	6.8%	9.6%	10.7%
HUC_18010205	Butte	9.1%	10.8%	14.8%	16.1%
HUC_18010206	Upper Klamath	5.4%	6.6%	8.9%	9.7%
HUC_18010207	Shasta	2.2%	2.6%	3.9%	4.4%
HUC_18010208	Scott	4.2%	4.9%	6.6%	7.6%
HUC_18010209	Lower Klamath	-0.7%	-0.9%	-1.1%	-1.2%
HUC_18010210	Salmon	1.0%	1.1%	1.3%	1.4%
HUC_18010211	Trinity	0.7%	0.8%	0.8%	0.9%
HUC_18010212	South Fork Trinity	0.8%	0.9%	0.7%	0.6%
Total Basin		6.1%	7.5%	10.3%	11.4%

All HUC8 subbasins show positive ET_c increases or no change, with the exception of the western-most HUC8 subbasin which exhibits slight decreases in ET_c under all scenarios by 2070 due to earlier harvest of grass hay.

The spatial distribution of projected NIWR percent change for different climate scenarios and time periods is shown in Figure 4-10, and a comparison of projected changes in annual NIWR for the central tendency climate scenario is provided in

Table 4-21. The NIWR incorporates growing season and non-growing season soil moisture gains and losses from precipitation, bare soil evaporation, and ET; therefore spatial variations in the distribution of NIWR percent change for different time periods and scenarios are a function of respective ET_c (Figure 4-9) and precipitation (Figure 4-6) distributions. For example, under the HD scenario precipitation is projected to decrease, whereas under the HW scenario precipitation is projected to increase. This results in NIWR increasing less in the HW scenario than in the HD scenario, though in both scenarios ETc changes are nearly identical.

Table 4-21. Comparison of projected changes in annual NIWR for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	16.1%	19.0%	26.1%	26.1%
HUC_18010202	Sprague	16.7%	18.4%	24.1%	25.0%
HUC_18010203	Upper Klamath Lake	10.5%	12.0%	17.2%	17.5%
HUC_18010204	Lost	8. 6%	9.4%	13.8%	14.2%
HUC_18010205	Butte	12.7%	13.9%	20.5%	20.4%
HUC_18010206	Upper Klamath	5.7%	5.7%	10.7%	10.4%
HUC_18010207	Shasta	3.5%	2.8%	4.8%	4.4%
HUC_18010208	Scott	5.5%	6.5%	8.7%	9.1%
HUC_18010209	Lower Klamath	-1.0%	-1.8%	-1.4%	-2.8%
HUC_18010210	Salmon	1.3%	1.4%	2.4%	1.8%
HUC_18010211	Trinity	0.8%	0.8%	1.1%	0.9%
HUC_18010212	South Fork Trinity	1.0%	0.1%	0.9%	-0.3%
Total Basin		9.0%	9.8%	14.1%	14.4%

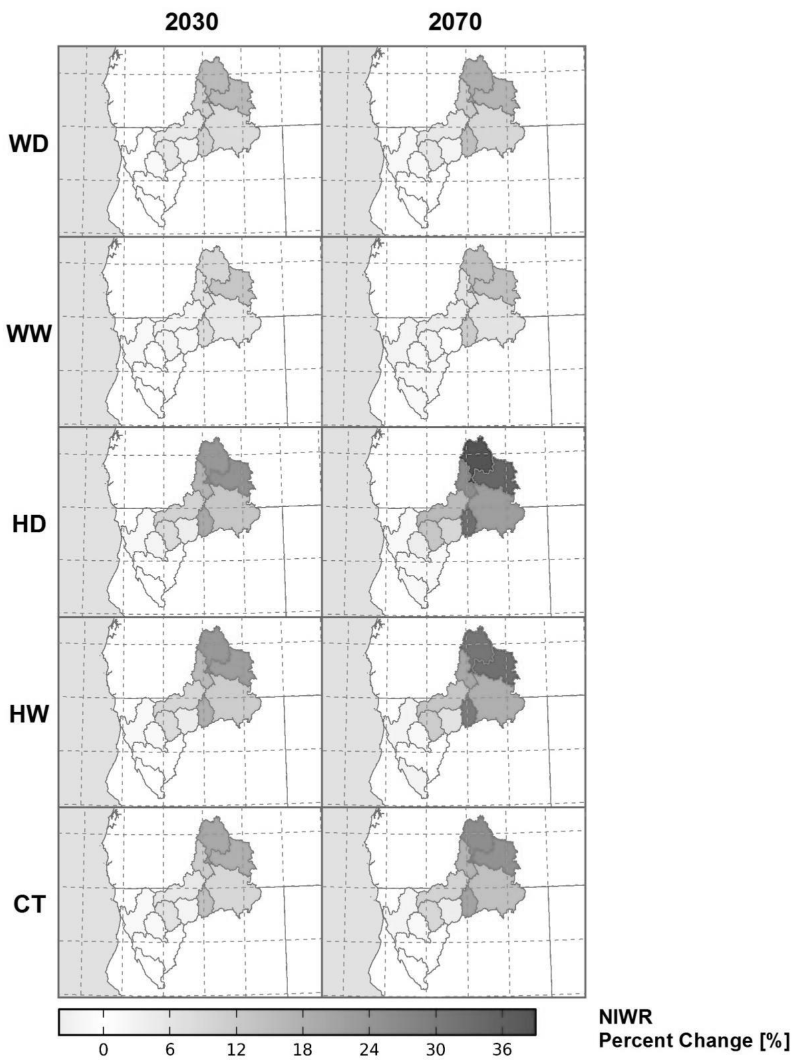

Figure 4-10. Klamath River Basin - Spatial distribution of projected net irrigation water requirements percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios)

Future Irrigation Demand Results

Assuming no change from current cropping patterns, the projected change in the central tendency scenario for the 2070s over the basin is 6-7% for reference ET (corresponding primarily to projected changes in temperature), while the projected change in crop ET is 10-11% (which incorporates changes in timing of crop growth and harvesting), and the projected change in NIWR is about 14% (which reflects changes in soil moisture throughout the year).

Figures 4-11, 4-12, and 4-13 illustrate the historical baseline and projected temporal distribution of mean daily ET_c for three perennial crops (alfalfa, pasture grass, and grass hay, respectively) under each CMIP5-based climate change scenario for the 2030s and 2070s. The values plotted in these figures are based on model results for Met Node OR4511 (NWS/COOP Klamath Falls Ag. Station).

Figure 4-11 shows slight but noticeable shifts in the growing season length and alfalfa cutting cycles relative to historical baseline conditions by the 2030s (left). By the 2070s time period (Figure 4-11, right) significant shifts in growing season length, crop development, and cutting cycles are noticeable relative to baseline conditions, with the HW and HD scenarios exhibiting the most extreme changes. These simulations assume established crops rather than first year plantings. Projected changes in ET_c are primarily realized through earlier green-up of alfalfa hay and changes in its cutting pattern. Senescence of the crop is delayed somewhat, but is primarily driven by day length. Maximum mean daily ET_c during the warmest part of the year is not projected to increase substantially, primarily because plants have a maximum rate at which they can evapotranspire despite further increases in temperature.

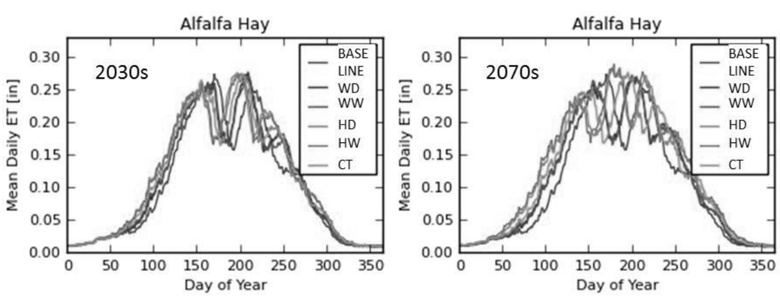

Figure 4-11. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily alfalfa evapotranspiration for all CMIP5-based scenarios and time periods

Figure 4-12 shows simulated mean daily ET_c of pasture grass; similar changes in green-up and increases in growing season length and ET_c are projected when compared to alfalfa, with the HW and HD scenarios having the most extreme seasonal changes.

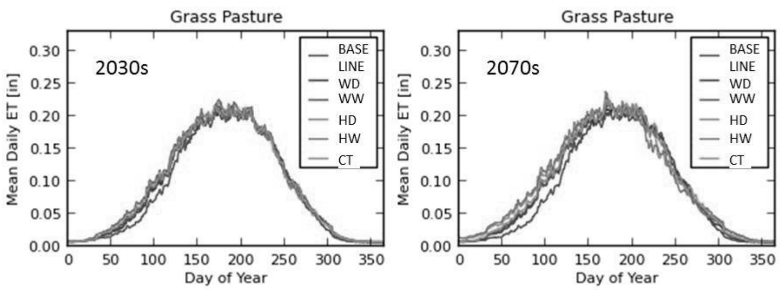

Figure 4-12. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily pasture grass evapotranspiration for all CMIP5-based scenarios and time periods

Figure 4-13 shows simulated mean daily ET_c of grass hay. As with alfalfa and pasture grass, earlier green-up and increased mean daily ET_c are slight for the 2030s and more pronounced for the 2070s. However, for the 2070s HW and HD scenarios, the overall growth period shifts forward rather than increasing in length. This is apparently due to the crop maturing earlier because of increased ET_c early in the growing season under higher temperatures.

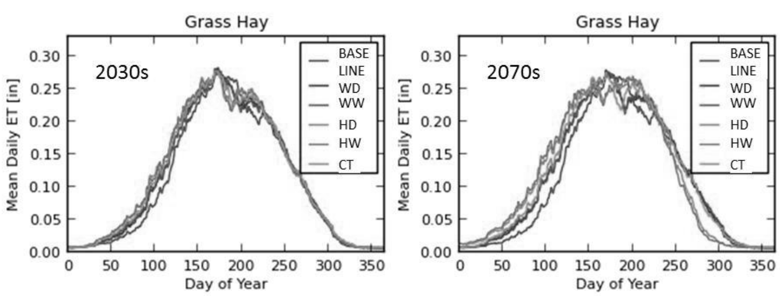

Figure 4-13. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily grass hay evapotranspiration for all CMIP5-based scenarios and time periods

Municipal and Industrial

Future M&I demand estimates are based on population growth projections and climate change scenarios. It is assumed current per capita demands will change as a function of changes in landscape irrigation demands due to climate change. Socio-economic factors that could cause changes in per capita demand, such as water conservation, reduced landscape areas, etc., are not accounted for in this chapter but are evaluated as potential adaptation strategies in Chapter 6. As previously discussed, 40 percent of total M&I use is assumed to be consumed through landscape irrigation.

The first step in estimating future M&I demands is to calculate the future base demands based on current demands and future population growth estimates (i.e., including growth scenario but no climate change scenarios). The base future demands are then adjusted for climate change effects on landscape irrigation. The adjustments were made using the same methods discussed previously for the future agricultural irrigation demand estimates. Specifically, the ET Demands model was used to calculate percent change in turf grass NIWR under the five climate change scenarios (WW, WD, CT, HW, and HD) using the two GCM projection datasets (CMIP3 and CMIP5). Forty percent of the base future demand estimate for a given period and scenario is increased based on the ET Demands model results.

The future M&I demand estimates for Klamath, Siskiyou, and Trinity Counties were calculated based on the 2005 USGS Water Use Program estimates and population growth rates published by the California Department of Finance[29] and Oregon Office of Economic Analysis.[30] Since the California and Oregon projections are for 2010 through 2060 and 2050 in five-year increments, respectively, it is assumed the growth rates from 2005 to 2015 are uniform as well for 2050–2070 (Oregon) and 2060–2070 (California). The product of the 2030 and 2070 county population growth rates and the 2005 county M&I estimates yields the base M&I demands for each county.

For the municipalities with domestic water supply systems in Del Norte, Humboldt, and Modoc Counties (Hoopa, Klamath, Newell, Orleans, and Willow Creek, all in California), county population growth rates published by the California Department of Finance were applied to the current (2010) population estimates for calculating future population estimates. The product of the 2030 and 2070 population projections and the current per capita demand estimates yields the base M&I demands for each of the systems in these municipalities.

As discussed above, each of the M&I base consumptive use estimates are adjusted for climate change. Figure 4-14 provides a summary of projected changes in M&I consumptive use for each county and each climate change scenario. The 2030 M&I consumptive use totals for all counties range from 9,759 AFY to

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[29] http://www.dof.ca.gov/research/demographic/reports/projections/P-1/
[30] http://www.dof.ca.gov/research/demographic/reports/projections/P-1/

10,065 AFY and the 2070 estimate totals range from 11,003 AFY to 11,747 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

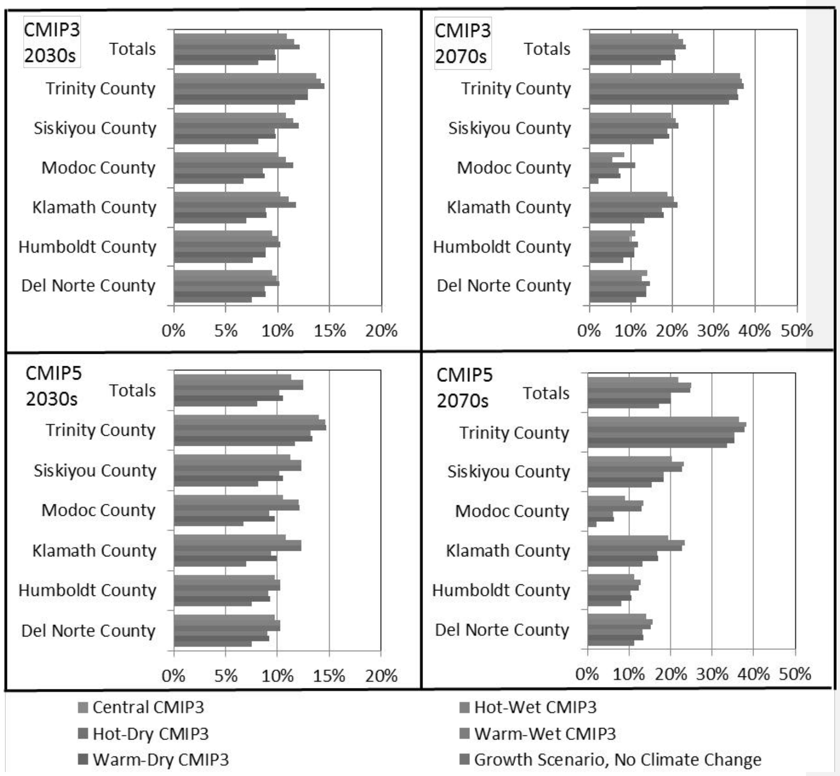

Figure 4-14. Summary of future municipal and industrial consumptive use estimates (percent change)

Rural Domestic

Future rural domestic water demand estimates were calculated based on population growth projections and climate change scenarios in the same manner as the M&I estimates discussed above. The same portion of total use for landscape irrigation is assumed (40 percent). Therefore, projections of future rural domestic use include only the consumptive portion of total use.

As discussed under Section 4.2, Current Demand, it is assumed the demands associated with the limited number of rural domestic water users in the portions of the basin in Del Norte and Humboldt Counties in California and Lake and

Jackson Counties in Oregon are negligible. Estimates were therefore calculated for Modoc, Siskiyou, and Trinity Counties in California and Klamath County in Oregon. The population projections used in the calculations are based on the 2005 USGS Water Use Program information and county population projections published by the California Department of Finance and Oregon Office of Economic Analysis.

Figure 4-15 provides a summary of projected change in rural domestic consumptive use for each county and each climate change scenario. The 2030s estimate totals for all counties range from 5,013 AFY to 5,190 AFY and the 2070s estimate totals range from 5,644 AFY to 6,030 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

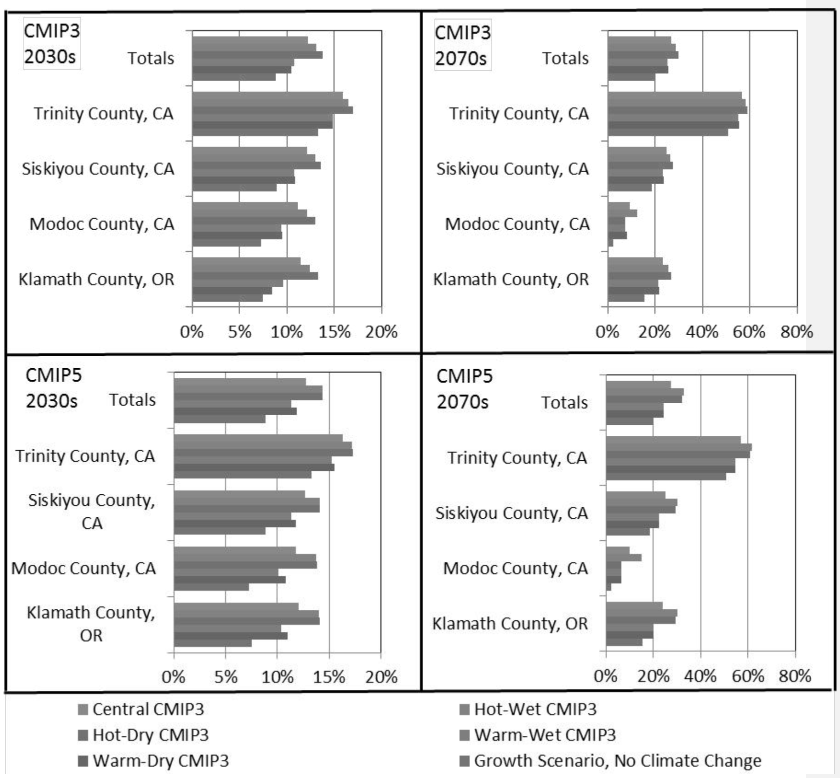

Figure 4-15. Summary of future rural domestic consumptive water use estimates (percent change)

4.3.3.2 Wetlands

Future wetland ET was computed based on projected mean daily alfalfa ET and pasture ET, using the same approach defined in Section 4.21, Human Influenced Consumptive Uses–Wetlands. Climate change scenarios using the HDe approach for each of the five quadrants of change for the 2030s and 2070s (using both CMIP3- and CMIP5-based projections) were also incorporated. The same relationships between wetland ET and alfalfa and pasture ET, according to the findings of Stannard et al. (2013), were used to determine projected mean annual wetland ET. Wetland ET is about 7 percent less than alfalfa ET during its average growing season and wetland ET is also about 18 percent greater than pasture ET during its average growing season. Mean annual wetland ET was computed using both relationships and averaged together for a single estimate.

Table 4-22 provides a summary of the resulting future wetland ET for each climate change scenario. The 2030s estimates range from 1,144,230 AFY to 1,228,916 AFY and the 2070s estimates range from 1,192,224 AFY to 1,319,673 AFY, compared with 1,089,061 AFY estimated for the mean annual historical wetland ET.

Table 4-22. Summary of basin-wide projected changes in wetlands ET

Future Period and Scenario	Mean Annual Wetland ET (AFY)	Mean Annual Wetland ET (Percent Change)
Historical	1,089,061	-
2030 Warm-Dry CMIP3	1,144,230	5%
2030 Warm-Dry CMIP5	1,155,489	6%
2030 Warm-Wet CMIP3	1,146,443	5%
2030 Warm-Wet CMIP5	1,163,648	7%
2030 Hot-Dry CMIP3	1,205,813	11%
2030 Hot-Dry CMIP5	1,228,916	13%
2030 Hot-Wet CMIP3	1,202,385	10%
2030 Hot-Wet CMIP5	1,225,025	12%
2030 Central CMIP3	1,175,143	8%
2030 Central CMIP5	1,191,936	9%
2070 Warm-Dry CMIP3	1,208,198	11%
2070 Warm-Dry CMIP5	1,192,224	9%
2070 Warm-Wet CMIP3	1,219,044	12%
2070 Warm-Wet CMIP5	1,203,335	10%
2070 Hot-Dry CMIP3	1,260,874	16%
2070 Hot-Dry CMIP5	1,300,472	19%
2070 Hot-Wet CMIP3	1,271,150	17%
2070 Hot-Wet CMIP5	1,319,673	21%
2070 Central CMIP3	1,237,064	14%
2070 Central CMIP5	1,246,884	14%

4.3.3.3 Lake and Reservoir Evaporation

The previously discussed CRLE model that was used to estimate historical baseline average evaporation rates was also used to estimate future average rates for the 2030s and 2070s periods. The same HDe climate change scenarios temperature and precipitation data described under the future agricultural irrigation demands discussion were input to the model. The model results include mean monthly evaporation and net evaporation (evaporation minus precipitation) rates for all of the reservoirs included in Table 4-14. The results for Upper Klamath Lake and Clair Engle Lake are discussed below, and the results for the other reservoirs are included in Appendix C, Section 5.0

Figures 4-16 and 4-17 show Upper Klamath Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and the historical baseline (1950–1999). The simulated impact of heat storage is negligible due to the shallow depth of Upper Klamath Lake. The magnitude of projected monthly evaporation and net evaporation increase is greatest during July, and least during fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Upper Klamath Lake is 5.5 and 5.4 percent (2.4 and 1.1 inches). Values for all scenarios are included in Appendix C, Section 5.0.

Figures 4-18 and 4-19 show Clair Engle Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and historical baseline (1950–1999). The simulated impact of heat storage due to the depth of Clair Engle Lake can be seen in the lag in peak evaporation relative to peak air temperatures (August versus July). Also, the relatively high precipitation rates result in negative net evaporation under all scenarios and the historical baseline. The magnitude of projected monthly evaporation and net evaporation increase is greatest during August, and least during the fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Clair Engle Lake is 5.7 and 9.0 percent (2.3 and -2.3 inches), respectively. Values for all scenarios are included in Appendix C, Section 5.0.

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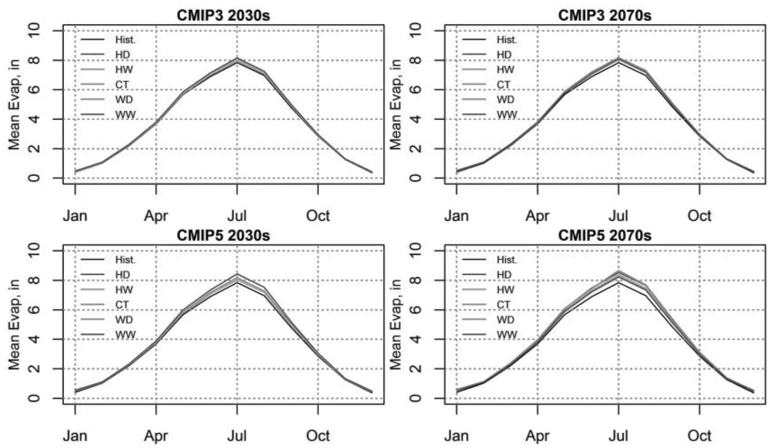

Figure 4-16. Summary projected mean monthly evaporation at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

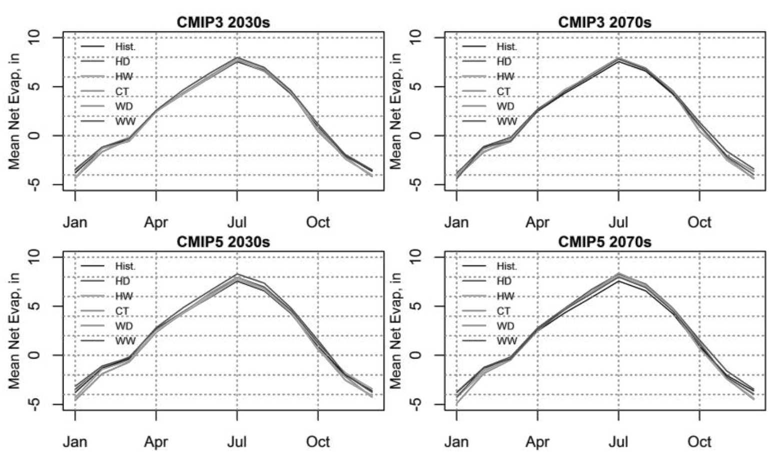

Figure 4-17. Summary projected mean monthly net evaporation (evaporation – precipitation) at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

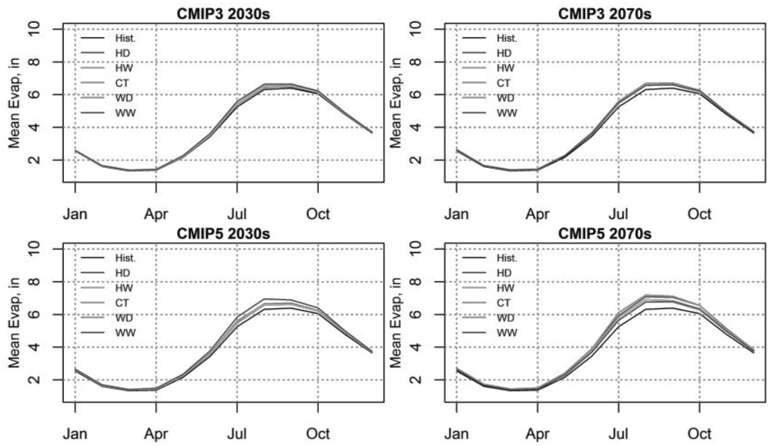

Figure 4-18. Summary projected mean monthly evaporation at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

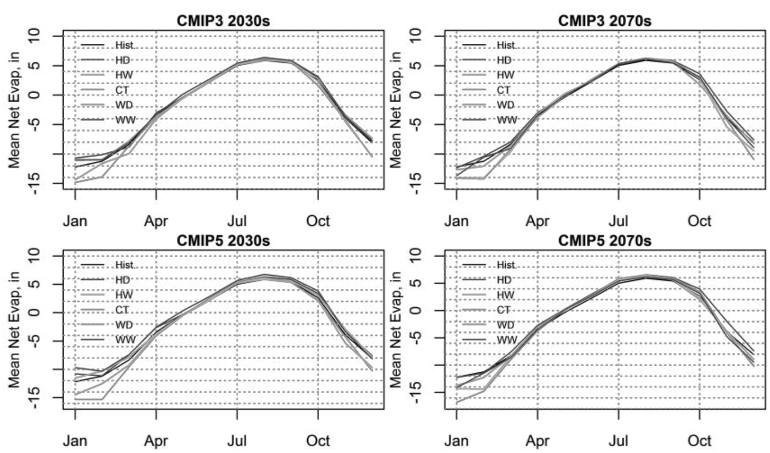

Figure 4-19. Summary projected mean monthly net evaporation (evaporation – precipitation) at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s

4.3.3.4 Non-Consumptive Uses

The effects of climate change on these uses (including recreation, environmental resources, hydropower, and aquaculture) are evaluated as part of the system reliability analysis in Chapter 5. In Chapter 5, the impacts are discussed in terms of factors such as exceedance of water quality criteria, flow or water level targets, and loss of power generation due to changing flows.

4.4 Uncertainties Associated with Impacts Assessment Approach

The Chapter 3 discussions on uncertainties associated with the various aspects of the Klamath River Basin Study water supply assessment covered many topics that also apply to the demands assessment. These topics include global climate forcing and simulation, climate projection bias correction and spatial downscaling, and climate projections from CMIP3 and CMIP5. Brief discussions of the limitations and uncertainties associated with quantification of water demands are presented below. A detailed discussion of uncertainties associated with the models used to estimate net irrigation water requirements (ET Demands) and reservoir evaporation (CRLE) are presented in Reclamation (2015) and are not detailed here.

Commented [GIM5]: I would add something here in light of the revised discussion in Section 3.9

4.4.1 Agricultural Irrigation

There are numerous uncertainties and limitations in modeling reference ET, crop ET, and net irrigation water requirements. One source of uncertainty is associated with underlying assumptions in modeling, such as static cropping patterns and farming practices. This study uses data provided by Reclamation's Klamath Basin Area Office for Klamath Project lands and the USDA crop land data layer for the remainder of the basin as the sources for quantifying the types of crops grown in the Klamath River Basin. It is assumed these crop types and quantities do not change in the modeling. Obviously, increases or decreases in the overall amount of irrigated area would result in respective changes in demands. Changes in crop choice may significantly affect future agricultural demands given the variability in water demand for different crop types.

Another source of uncertainty is the weighted average soil conditions used in the estimation of net irrigation water requirements. Precipitation runoff and soil water holding capacity are a function of soil type, and soil types can vary significantly even within a single irrigated parcel of land. The degree of uncertainty in the method used depends on the variability of soil types within each HUC8 subbasin for which a weighted average soil type was calculated, as described in Reclamation (2015).

Climatic data used in this basin study analysis were limited to daily maximum and minimum temperatures and daily precipitation; therefore solar radiation, humidity, and windspeed were approximated for baseline and future time periods using empirical approaches. Solar radiation was simulated for baseline and future

periods based on empirical relationships of differences between daily maximum and minimum air temperatures, where maximum air temperature generally decreases during cloud cover, and minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night. Integration of potential changes in solar radiation, and evaluating the potential impact of such changes on irrigation water demands, were not addressed in this analysis.

Historical agricultural weather station data were used to estimate the spatial distribution of baseline and projected mean monthly dewpoint depression and windspeed. Given the uncertainties and limited availability in future projections of humidity and windspeed, mean monthly dewpoint depression and windspeed were considered static for future periods. While there is considerable uncertainty in projecting future reference ET, estimation of reference ET for historical periods using the assumptions outlined above was shown to be robust when compared to agricultural weather station estimated reference ET.

4.4.2 Municipal and Industrial and Rural Domestic

Uncertainties associated with M&I and rural domestic demands are related to the assumed population projections and per capita demand rates used, and the assumed landscape irrigation portion of the overall demand (40 percent).

4.4.3 Wetlands

Evapotranspiration from wetlands is difficult to quantify and a limited number of studies have been conducted in this area of research. Wetlands are biologically diverse and quantification of ET requires expensive long-term monitoring. Existing studies often based their findings on data collected over a limited time period, generally a few years, contributing to the uncertainty around their estimates. The Klamath River Basin Study utilizes available studies to estimate mean annual wetland ET. Although there is relatively high uncertainty surrounding the estimates of wetland ET in this study, they generally corroborate other existing studies and provide a best estimate of mean annual wetland ET.

4.4.4 Reservoir Evaporation

Uncertainties in estimated reservoir evaporation are largely centered on CRLE energy balance considerations, specifically heat storage and advection of heat in air and water into and out of the reservoir. One important limitation of the CRLE model is its reliance on energy balance without consideration of the effects of windspeed on evaporation. However, one could argue that using an approach that heavily relies on windspeed, and is therefore extremely sensitive to uncertainties in windspeed (i.e., the aerodynamic-mass transfer or combination approach), may actually increase evaporation uncertainty, especially under future climates where projections of near surface local scale windspeed estimates are extremely uncertain.

It is significant that reservoir evaporation and net evaporation (evaporation minus precipitation) demands were estimated in terms of annual rates or depths rather

than volumes. These rates were estimated based on average historical conditions and a more rigorous analysis would be required to model evaporation under predicted future reservoir conditions. Future research in the Klamath River Basin could involve adjusting the CRLE model to accommodate projections of future reservoir conditions.

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Chapter 5
Klamath River Basin Study
System Reliability Analysis

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5.1 Introduction

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to work toward future water security. Reclamation developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (P.L. 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management. Studies are typically completed within a three-year timeframe. The purpose of the Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances.

This chapter discusses the methodology for evaluating gaps in water supply and demand and summarizes the reliability of the Klamath River system in achieving numerous defined measures, based on both historical data and projected future conditions.

Previous chapters of the Basin Study include an introduction and background for the study (Chapter 1), a discussion of various interrelated activities in the watershed (Chapter 2), an assessment of historical and future water supply in the watershed (Chapter 3), and an assessment of historical and future water demand in the watershed (Chapter 4). Chapter 6 discusses the development and evaluation of adaptation strategies for reducing gaps in water supply and demand within the system reliability framework discussed in this chapter. Figure 5-1 provides an overall schematic of the Basin Study approach to provide context for Chapter 5.

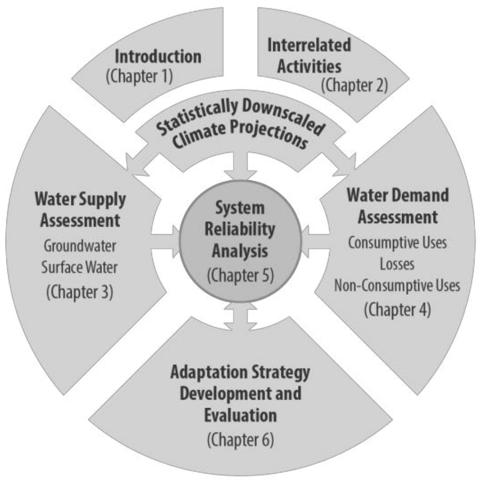


Figure 5-1. Overall approach of Klamath River Basin Study, highlighting Chapter 5

5.2 System Reliability Methodology

The Basin Study developed a framework for evaluating projected future water supply and demand conditions in a changing climate. This framework includes scenarios for characterizing projected future conditions, along with development and implementation of connected modeling components, with the end goal of evaluating system risk and reliability in the basin. Additionally, the Basin Study system risk and reliability analysis evaluates impacts of climate change on non-consumptive uses, which are those that do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.) and water needs to support fish and wildlife and hydropower production, among others.

This section briefly reviews the scenarios developed and corresponding modeling components implemented to provide inputs to a water management model. More detailed discussions of historical and projected water supply and demand are provided in Chapters 3 and 4, respectively. This section then provides a detailed description of the tools developed to evaluate system reliability and potential vulnerabilities to climate change impacts. Results from the analysis are evaluated using basin-wide response variables and defined measures to quantify and summarize projected changes in system reliability due to climate change.

5.2.1 Characterizing Historical and Future Conditions

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020–2049) and the 2070s (represented by the mean from 2060–2089). Future projections are compared with a historical reference period of 1950–1999 to evaluate the effects of climate change on water supply.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. The same dataset was used for analysis of historical conditions in the Basin Study. Historical trends in April 1 SWE, total annual runoff, total annual ET, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model (described in detail in Chapter 3).

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50 year period). All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999. Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide. Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent. ET, as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide. Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole. The only statistically significant trend at the 95th percentile level computed with the historical data is mean annual temperature.

The development of climate change scenarios is described in Chapter 3, Section 3.5.1.1 Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). The Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes available climate projections to derive a smaller number of climate change scenarios to inform long term planning. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios for each of two sets of projections (CMIP3 and CMIP5). These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT). These scenarios were derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d).

Projections of future water supply and demand using the above-discussed climate change scenarios and evaluated in Chapters 3 and 4, respectively, are briefly summarized below. Following this brief summary is a discussion of the methodology used to evaluate projected changes in managed streamflow and water temperature at various locations throughout the basin.

5.2.1.1 Water Supply

- By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

- Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

- A decrease in April 1 SWE is projected on the order of 34 to 40 percent for the 2030s and close to 60 percent for the 2070s, and projected increases in annual runoff are 7 to 12 percent for the 2030s and 14 to 15 percent for the 2070s. Projected increases in mean annual runoff are offset by projected changes in April 1 SWE, primarily due to projected increases in mean annual precipitation,

- For sub-basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

- An increase in groundwater head is projected in mountainous recharge areas of the Upper Klamath Basin (less than 9 percent), as is a change in groundwater discharge to streams, while little change is expected in populated interior parts of the basin.

5.2.1.2 Water Demands (Human Influenced)

- Agricultural irrigation demand (surface and groundwater) is the largest human influenced consumptive use in the basin.

- Projected changes in total consumptive uses are 12 or 13 percent (CMIP3 and CMIP5 scenarios, respectively) for the 2030s and 17 or 18 percent for the 2070s. Consumptive uses include agricultural irrigation, net reservoir evaporation, municipal and industrial (M&I) and rural domestic demands, and wetlands.

- The effects of climate change on other non-consumptive uses including recreation, environmental resources, hydropower, and aquaculture are evaluated as part of this chapter.

5.2.2 Basin-Wide Responses

The evaluation of climate change impacts on system risk and reliability has two primary components: basin-wide system response at various basin locations, and specific performance measures that have been identified through discussions with regional resource managers, stakeholders, and others. Evaluation of basin-wide system response provides a general understanding of projected changes in managed conditions as a result of climate change and implemented adaptation strategies. Evaluation of system response to quantified measures provides a deeper understanding of climate change impacts on specific resources relevant to water management in the basin.

Basin-wide response variables include mean monthly conditions for the following locations:

- Mean monthly Upper Klamath Lake storage
- Mean monthly inflow to Klamath River at Keno
- Mean monthly streamflow, Klamath River at Iron Gate
- Mean monthly streamflow, Klamath River at Orleans, California
- Mean monthly streamflow, Klamath River near Klamath, California
- Mean monthly water temperature in the Klamath River near Klamath, California

This report includes analysis of historical and projected future changes in these basin-wide response variables, according to the developed Basin Study modeling framework. Subsequently, in Chapter 6, basin-wide response variables are evaluated for each of the adaptation strategies selected for exploring ways to reduce any identified water supply and demand gaps. Performance measures are described in more detail below.

5.2.3 Performance Measures

Performance measures are used to evaluate historical and future vulnerabilities to meeting water needs in the basin, and to facilitate the comparison of adaptation strategies to reduce any identified imbalances in water supply and demand.

Performance measures have been identified in accordance with the Basin Study Framework guidance document (Reclamation, 2009c) and span numerous resource categories, which include:

- Water deliveries – the ability for water to be delivered to water users
- Hydroelectric power resources
- Recreational resources – including Reclamation facilities and parts of the watershed impacted by Reclamation operations

- Ecological resources – including fish and wildlife habitat; applicable species listed as an endangered, threatened, or candidate species under the Endangered Species Act of 1973; species and habitat of cultural importance; and flow and water dependent ecological resiliency
- Water quality resources
- Flood control

Measures for each category were arrived at based on input from stakeholders and resource managers in the basin. Table 5-1 summarizes the performance measures. The following paragraphs describe each measure in more detail.

Table 5-1. General description of performance measures

Resource Category	Measure Description	Location(s)	Measure Details
Water supplies	Total Klamath Project supply	Klamath Project	Calculated under 2013 Biological Opinion operating criteria. Compare result with full season Klamath Project supply of 390,000 acre-feet.
	Total Upper Klamath Lake seasonal supply	Upper Klamath Lake	End of February storage plus actual March through September inflow at Upper Klamath Lake
	Mean annual tributary flow	Shasta River; Scott River	Mean annual flow at USGS gages (USGS 11517500 Shasta River near Yreka; USGS 11519500 Scott River near Fort Jones)
Hydroelectric power resources	Hydropower production	Sum of J.C. Boyle power, COPCO 1 power, COPCO 2 power, Iron Gate power	Mean annual hydropower production summed over these facilities[31]
	Volume of spill	J.C. Boyle, COPCO 1, Iron Gate	Mean annual spill volume based on water year[1]
	Frequency of spill	J.C. Boyle, COPCO 1, Iron Gate	Mean number of spill days per water year at these facilities[1]
Recreational resources	Mean fishing days per year	Various mainstem Klamath River reaches	Mean number of days per year that flows are within acceptable ranges for select river reaches

[31] Source: PacifiCorp

Table 5-1. General description of performance measures

Resource Category	Measure Description	Location(s)	Measure Details
	Mean boating days per year	Various mainstem Klamath River reaches	Mean number of days per year that flows are within acceptable ranges for select river reaches
Ecological resources	Salmonid success	Shasta River; Scott River	Flow thresholds throughout the year[32]
	Delivery to refuge	Lower Klamath National Wildlife Refuge	Mean annual water delivery to refuge[33]
	Pool elevation	Clear Lake; Gerber Reservoir	Minimum elevation thresholds[34]
Water quality	Water temperature	Klamath River	Maximum weekly average temperature (MWAT)
Flood control	Frequency of flood control release	Upper Klamath Lake	Mean number of days per year that flood control releases are made from Upper Klamath Lake[35]
	Mean annual flood control release volume	Upper Klamath Lake	Mean annual volume of flood control releases from Upper Klamath Lake[5]
	Date of seasonal peak flow	J.C. Boyle, COPCO 1, Iron Gate	Mean date of the center of mass of the annual flow volume (by water year) at select locations[1]

5.2.3.1 Water Supplies – Klamath Project Water Supply

There are two measures associated with Klamath Project water supply. The first measure is computed as the mean annual water supply to the Klamath Project, expressed as a percentage. The value may be compared with a full supply quantified as 390,000 acre-feet.

The second measure is computed as the sum of the end of February Upper Klamath Lake storage and the actual March through September Upper Klamath Lake inflow, averaged across the simulation years and expressed in units of a thousand acre-feet. The measure represents the total seasonal availability of water supply to be distributed among project responsibilities.

5.2.3.2 Water Supplies – Mean Annual Tributary Flow in Shasta and Scott Rivers

This measure is computed for two locations: USGS gages Shasta River near Yreka (11517500) and Scott River near Fort Jones (11519500). The measure is computed as the mean annual streamflow at these two locations. Effectively, the simulated streamflows represent the balance of supply and demand in these two

[32] Source: McBain and Trush (2014)
[33] Source: Klamath Basin National Wildlife Refuge Complex
[34] Source: Klamath Basin Area Office
[35] Source: Reclamation (2012d)

tributary watersheds to the Klamath River. Units are in cubic feet per second (cfs).

5.2.3.3 Hydroelectric Power Resources – Hydropower Production
This measure is computed as the sum of mean annual hydropower production at J.C. Boyle reservoir, COPCO 1 reservoir, COPCO 2 reservoir, and Iron Gate reservoir. Units of hydropower production are megawatts.

5.2.3.4 Hydroelectric Power Resources – Spill Volume
This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean spill per year in cfs.

5.2.3.5 Hydroelectric Power Resources – Spill Frequency
This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean number of days per year that each of the reservoirs have spill.

5.2.3.6 Recreational Resources – Mean Annual Fishing Days
This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow (by the surface water management model) is within the target ranges for fishing in each river reach. Table 5-2 lists the recommended flow ranges for fishing.

Table 5-2. Recommended target flow ranges for fishing within select reaches of the Klamath River

River Reach	Flow Target Ranges (cfs)
Keno Reach	200-1,500
J.C. Boyle	200-1,000
Hell's Corner Reach	200-1,500
COPCO 2 Bypass Reach	50-600
Iron Gate to Scott River	800-4,000
Scott River to Salmon River	800-4,000
Salmon River to Trinity River	800-10,000
Trinity River to ocean	1,000-18,000

Source: Interior and CDFG, 2012

5.2.3.7 Recreational Resources – Mean Annual Boating Days
This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow by the surface water management model is within the target ranges for river boating in each river reach. Table 5-3 lists the recommended flow ranges for river boating.

Table 5-3. Recommended target flow ranges for boating within select reaches of the Klamath River

River Reach	Flow Target Ranges (cfs)
Keno Reach	1,000-4,000
J.C. Boyle	1,300-1,800
Hell's Corner Reach	1,000-3,500
COPCO 2 Bypass Reach	600-1,500
Iron Gate to Scott River	800-4,000
Scott River to Salmon River	800-7,000
Salmon River to Trinity River	800-10,000
Trinity River to ocean	1,000-18,000

Source: Interior and CDFG, 2012

5.2.3.8 Ecological Resources – Salmonid Success in Shasta and Scott Rivers

This measure is computed at two locations: USGS gages Scott River near Fort Jones (11519500) and Shasta River near Yreka (11517500). The measure compares simulated daily flow to quantified dry year flow targets recommended by McBain and Trush (2014) for the Shasta River. A dry year has an exceedance probability of between 61 and 100 percent. The measure is computed as the total number of days in a model simulation that dry year flow targets are met or exceeded, divided by the total number of days in the simulation and presented as a percentage. Dry year flow targets recommended by McBain and Trush (2014) are summarized below in Table 5-4. Note that the flow targets were developed for the Shasta River, where mean annual flow (188 cfs) is less than one third that of the Scott River (669 cfs). However, for purposes of this analysis the same threshold flows were applied for the Scott River to explore the frequency of meeting those same target flows in the Scott River.

Table 5-4. Dry Year (61–100 percent exceedance) flow targets for salmonids

Time Period	Dry Year Target (cfs)
January 1 – March 31	135
April 1 – May 15	170
May 16 – June 15	150
June 16 – September 15	70
September 16 September 30	70-90
October 1 – October 16	125
October 17 – October 30	125-150
October 31 – December 31	150

Source: McBain and Trush 2014

5.2.3.9 Ecological Resources –Water Delivery to Lower Klamath National Wildlife Refuge

This measure is computed as the mean annual water supply to Lower Klamath National Wildlife Refuge as simulated by the surface water management model. The measure is expressed in acre-feet.

5.2.3.10 Ecological Resources – Pool Elevation at Clear Lake and Gerber Reservoirs

This measure is computed at two locations: Clear Lake and Gerber Reservoirs. The measure compares simulated pool elevations at these locations with minimum pool elevations quantified for survival of Lost River and shortnose suckers. Minimum pool elevation for Clear Lake is 4,520.6 feet, while the minimum pool elevation for Gerber Reservoir is 4798.1 feet. The measure is computed as the mean percent of days that simulated pool elevations are at or above target pool elevations.

5.2.3.11 Water Quality – Water Temperature

This measure is computed as the maximum weekly average temperature (MWAT) in the mainstem Klamath River. The MWAT is the highest seven-day moving average of the daily mean river temperature. This measure is computed using the RBM10 stream temperature model developed by Perry et al. (2011). Details of the river temperature modeling approach and implementation are discussed in Section 5.3.2, System Reliability Model Development – Water Temperature Model. The MWAT is computed for each year and the mean of these temperatures across the simulation years is presented as the measure. Table 5-5 summarizes classifications of Poor to Very Good conditions for fish, along with associated temperature ranges, provided in the SONCC ESU coho salmon recovery plan (NMFS 2012).

Table 5-5. Maximum weekly average temperature recommendations from the SONCC ESU salmon recovery plan

Maximum Weekly Average Temperature (MWAT) Classification	Temperature Range (degrees C)	Temperature Range (degrees F)
Poor	> 17.6	> 63.68
Fair	16-17	60.8-62.6
Good:	15-16	59-60.8
Very Good	< 15	< 59

Source: NMFS 2012, Appendix B

5.2.3.12 Flood Control – Flood Control Release Frequency

This measure is computed as the mean annual percent of days where release from Upper Klamath Lake is specifically for flood control purposes. The unit of the measure is percent of days.

5.2.3.13 Flood Control – Flood Control Release Volume

This measure is computed as the mean annual volume of releases from Upper Klamath Lake specifically for flood control purposes. The unit of the measure is thousands of acre-feet (KAF).

5.2.3.14 Flood Control – Date of Seasonal Peak Flow

This measure is computed as the mean date of the center of mass of the annual flow volume (by water year) at select locations. The center of mass is defined as

the time at which half of the mean annual flow has passed the location of interest. The measure is presented as the mean date over the simulation period.

5.3 System Reliability Model Development

This analysis utilizes developed historical and future water supply and demand as input to a system risk and reliability model framework. The modeling framework involves two main components: the implementation of a surface water management model to generate simulated managed streamflow throughout the basin, and the implementation of a river temperature model to generate simulated water temperature in the mainstem Klamath River. The modeling components are described below in more detail.

5.3.1 Surface Water Management Model

A RiverWare surface water management model (Zagona et al., 2001) was developed for use by the Klamath River Basin Study. The RiverWare software platform allows for evaluation of river flows based on rule-based operations, using logic statements and assigned rule priorities. The RiverWare platform has been used in many other studies conducted by Reclamation and others (e.g., Colorado River Basin Water Supply and Demand Study [Reclamation, 2012e]; St. Mary River and Milk River Basins Study [Reclamation, 2012f]).

The Klamath Basin RiverWare model is a daily timestep model based on two existing models for the Upper Klamath Basin and Lower Klamath Basin. The existing Upper Klamath Basin model, commonly referred to as the Klamath Basin Planning Model (KBPM), was developed to support the ESA consultations over the impacts of Klamath Project operations on the endangered SONCC ESU coho salmon (Reclamation, 2012d). The existing Lower Klamath Basin model was developed to support the environmental impacts assessment for removal of four of the mainstem Klamath River dams (Interior, Department of Commerce, NMFS, 2012).

The Klamath Basin RiverWare model encompasses the entire watershed including tributaries of Upper Klamath Lake, the Lost River system, and major Klamath River tributaries such as the Shasta River, Scott River, Indian Creek, Salmon River, and Trinity River. The model includes representation of eight reservoirs: Upper Klamath Lake, Clear Lake, Gerber Reservoir, Lake Ewauna, J.C. Boyle Reservoir, COPCO 1 Reservoir, COPCO 2 Reservoir, and Iron Gate Reservoir.

The Klamath Basin RiverWare model was developed over a historical time period of water years 1961 through 2013 to facilitate comparison of results with the KBPM model. The historical model incorporates historical water demand information, and simulated water supply information from the water supply assessment in Chapter 3 in order for model validation to be performed. Once simulated flows were reached that sufficiently compared with results from the KBPM model, a separate historical model was developed using a period of record

of water years 1969 through 1999. The latter model incorporates simulated historical information from the water supply and water demands assessments in Chapters 3 and 4, respectively. This model was used as the basis for comparison of simulated streamflows under the historical climate to those under climate change scenarios.

The level of detail of the Klamath Basin RiverWare model allows for evaluation of Klamath River flows and Klamath Project operations under the current 2013 non-jeopardy Biological Opinion for SONCC ESU coho salmon, as well as evaluation of climate change impacts on other parts of the basin, including the Lost River and major Klamath River tributaries listed above.

Inputs to the Klamath Basin RiverWare model include the following:

- simulated natural surface hydrology from the VIC hydrologic model at various locations within the basin
- simulated groundwater discharge to streams in the Upper Klamath Basin as produced by the Gannett et al. (2007) MODFLOW model
- agricultural irrigation water requirements by 8-digit hydrologic unit code (HUC) throughout the Klamath Basin as produced by the water demands assessment (Chapter 4)
- net reservoir evaporation rates as produced by the water demands assessment (Chapter 4)
- M&I and rural domestic demands as produced by the water demands assessment

Outputs from the Klamath Basin RiverWare model include the following:

- Simulated managed flow at various locations in the Klamath Basin
- Reservoir storage and elevations
- Deliveries to the Klamath Project, Lower Klamath National Wildlife Refuge (LKNWR), etc.
- Hydropower generation

5.3.2 Water Temperature Model

The Klamath River Basin Study incorporates analysis of historical and projected future Klamath River temperature using an existing river temperature model developed by Perry et al. (2011). The river temperature model, called River Basin Model-10 (RBM10), was developed for the Secretarial Determination on removal of four hydroelectric dams on the Klamath River. It simulates water temperatures in the mainstem Klamath River from the Link River to the mouth. In this

application, water temperatures are computed at the Klamath River near Klamath, California.

RBM10 uses a simple equilibrium flow model, assuming discharge in each river segment on each day is transmitted downstream instantaneously. The model uses a heat budget formulation to quantify heat flux at the air-water interface. Inputs for the heat budget were calculated from daily-mean meteorological data including net shortwave solar radiation, net longwave atmospheric radiation, air temperature, wind speed, vapor pressure, and a psychrometric constant needed to calculate the Bowen ratio.

For the Klamath River Basin Study application, meteorological inputs used as part of the water supply assessment described in Chapter 3 were adjusted to match the statistics of the meteorological data used by Perry et al. (2011) in their study of the impacts of climate change and dam removal on Klamath River water temperatures. Input streamflows were taken directly from the Klamath Basin RiverWare model at locations consistent with the Perry et al. (2011) study. It should be noted that input streamflows were increased by 10 cfs in some Upper Klamath Basin reaches to prevent negative streamflows in the mainstem Klamath River. Negative Klamath River flows were possible due to the difference in handling of streamflow routing by the RBM10 and Klamath River Basin RiverWare models.

5.4 System Reliability and Impacts Assessment

Historical and projected future reliability of the Klamath River Basin water supply is summarized in two ways: through basin-wide response variables, and through identified reliability measures that were defined for six resource categories. This methodology was previously described in Section 5.2, System Reliability Methodology.

This chapter summarizes historical and projected changes in system reliability due to climate change alone. Chapter 6 discusses how various basin-wide responses and select measures may change as a result of implementing adaptation strategies.

Impacts on Reservoir Storage

Mean end of month storage in Upper Klamath Lake generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, end of month reservoir storage did not historically fluctuate substantially through the year. Projections for the 2030s and 2070s indicate peak storage is likely to remain about the same or increase slightly.

5.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of historical and projected future basin-wide responses to water supply and demand allows for a general understanding of how the basin may respond as a result of climate change. Historical and projected future changes in water availability of the managed Klamath River system are provided below. Data supporting the following figures are provided in Appendix D.

5.4.1.1 Upper Klamath Lake Storage

Mean monthly end of month (EOM) storage in Upper Klamath Lake is summarized in Figure 5-2. Maximum storage historically occurs at the end of May, while minimum storage occurs in November. Under the climate change scenarios, mean EOM storage generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s, or even two months under the HW scenario. In addition, all scenarios experience a deeper drawdown of Upper Klamath Lake (UKL) than under simulated historical conditions and show minimum elevations in October compared to November (historical). Results in Figure 5-2 show that projected mean EOM storage is less under all future scenarios than under the simulated historical reference period. This result is likely due to use of the 2013 BiOp management criteria for all scenarios. Many management decisions rely on static look-up tables, which lack the flexibility to respond to different hydrologic conditions such as changes in Upper Klamath Lake inflow timing.

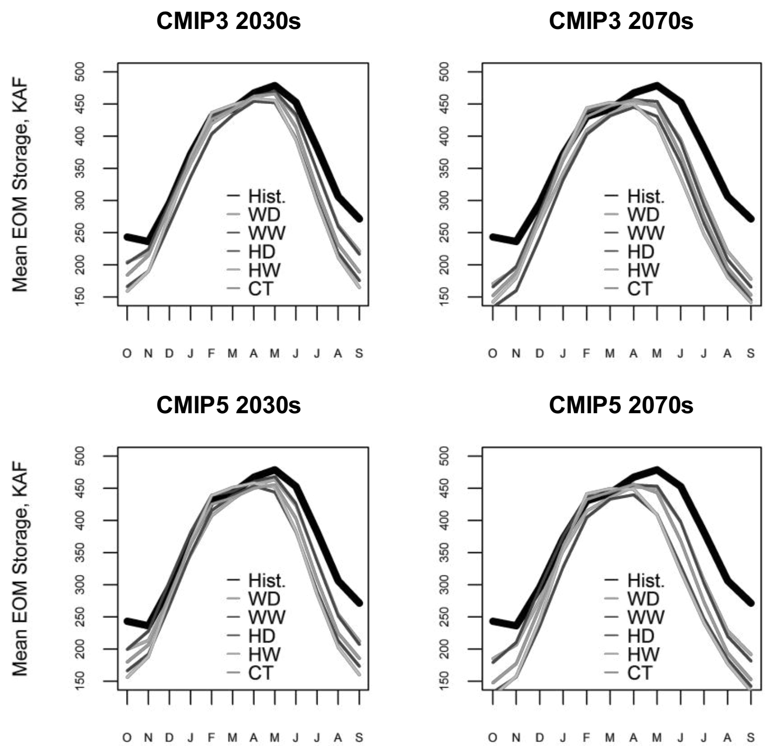


Figure 5-2. Historical and projected future mean monthly Upper Klamath Lake storage (AF)

5.4.1.2 Keno Dam Inflow

Historical and projected future mean monthly inflow to Keno Dam is summarized in Figure 5-3. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. For the 2030s, the CT scenario indicates slightly higher peak flows while the HW and WW scenarios appear to have the highest increase in peak flow; the HD and WD scenarios show similar or slightly reduced peak flows. By the 2070s managed inflows to Keno Dam also appear to shift toward higher flows earlier in the year. Results indicate mean annual volumes increase under the wetter scenarios (HW and WW). Overall increases in Keno Dam

Mean Monthly Flow

Projections indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

inflow are primarily driven by increases in inflows to Upper Klamath Lake and thereby increases in Link River Dam outflows.

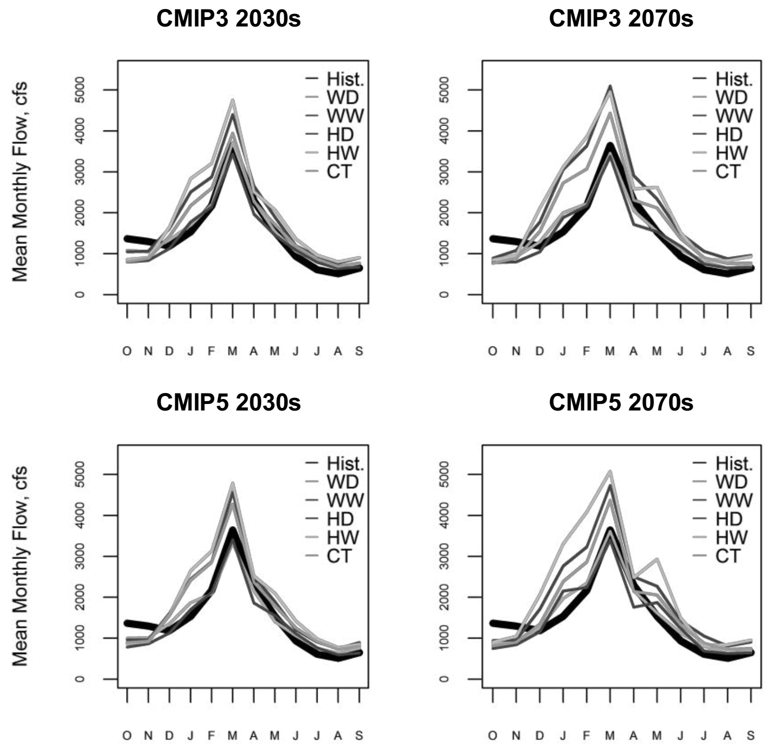


Figure 5-3. Historical and projected future mean monthly managed inflows to Keno Dam (cfs)

5.4.1.3 Iron Gate Reservoir Storage

Historical and projected future mean monthly Iron Gate Reservoir storage is summarized in Figure 5-4. Historically, EOM reservoir storage would peak in March and have its lowest storage in the summer months. Reservoir storage historically did not fluctuate substantially through the year, generally varying between about 55,000 acre-feet and almost 57,000 acre-feet. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase; none of the climate change scenarios indicate a reduction in peak reservoir storage.

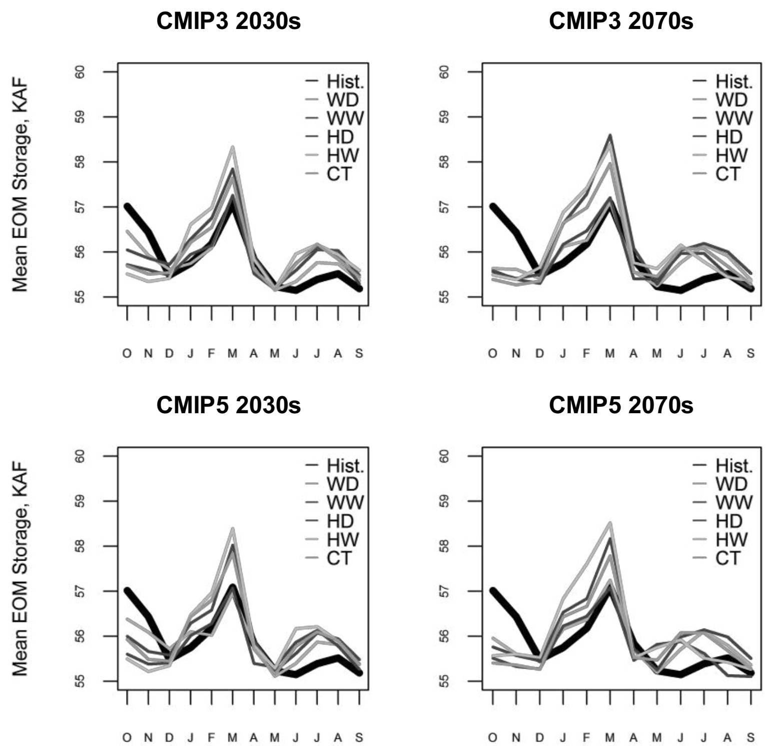


Figure 5-4. Historical and projected future mean monthly Iron Gate Reservoir storage (KAF)

5.4.1.4 Iron Gate Reservoir Outflow

Historical and projected future mean monthly outflow from Iron Gate Dam is summarized in Figure 5-5. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. Historical and projected changes in outflow at Iron Gate Dam correspond with those found at Keno, primarily due to their conjunctive management under the 2013 Proposed Action for Klamath Project operations. Projected changes in peak outflow are similar to Keno inflow in that the WW and the HW scenarios suggest the greatest increases. Also, particularly for the 2070s, substantial increases in flow during the months of January and February are projected. Differences between mean monthly inflows at Keno and outflow at Iron Gate from about May through September, namely projected increases at Keno and projected decreases at Iron Gate, are due to a combination of operating criteria and hydrology. Local inflows between Keno and Iron Gate are projected to decrease, which may contribute to the differences

during this period. Also during these months environmental flow requirements often govern operations, and these requirements are generally accounted for at Iron Gate Dam to maintain minimum flows. These operating criteria may result in differences in projected flows at the two locations.

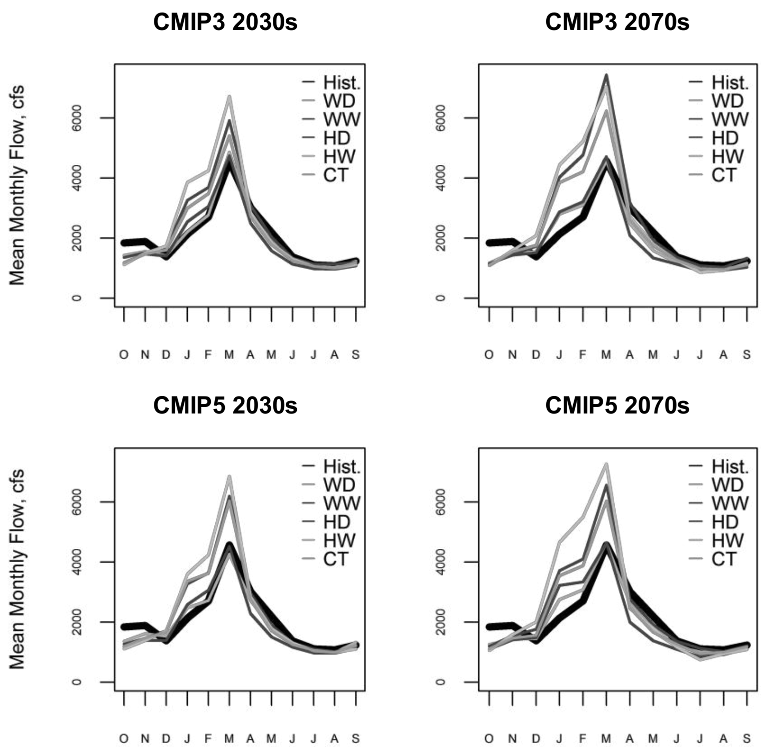


Figure 5-5. Historical and projected future mean monthly Iron Gate Reservoir outflow (cfs)

5.4.1.5 Shasta River Flow

Historical and projected future mean monthly flows in the Shasta River near Yreka are presented in Figure 5-6. Historical mean monthly flows exhibit a double peak, in January and again in March, the first corresponding with the period of seasonal peak rainfall and the second corresponding with snowmelt. The lowest flows occur during August. Projections of climate change indicate a range of increased snowmelt runoff contributing to streamflow (HW and WW scenarios) to decreased snowmelt runoff for the drier scenarios (HD and WD), with the central tendency similar or slightly less than historical. Flows during the

rainfall peak period are projected to increase for all but the WD scenario for the 2030s time period. By the 2070s, all scenarios project increased rainfall-driven peak flow in January. In addition, all but the WW scenario indicate reduced late spring flows, likely due to decreased snowpack (except for Mount Shasta, which is projected to experience increased snowpack due to increased precipitation and high elevations).

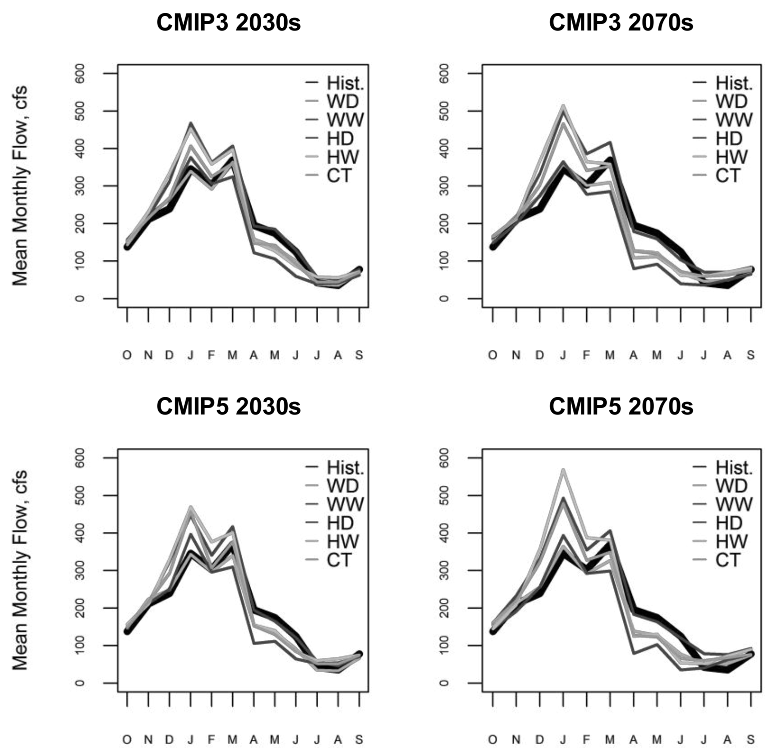


Figure 5-6. Historical and projected future mean monthly flow in the Shasta River near Yreka (cfs)

5.4.1.6 Scott River Flow

Historical and projected future mean monthly flows in the Scott River near Fort Jones are presented in Figure 5-7. The Scott River is a more rain-dominated watershed than the neighboring Shasta River watershed to the east. Historical mean monthly flows reflect a mixture of rain and snow during winter and early spring months, with seasonal peak flows occurring in March but closely followed by January and February. Climate change projections for both the 2030s and 2070s time periods, for both CMIP3 and CMIP5 based projections, indicate increased winter flows as a result of corresponding projected increases in precipitation. Also, the snowmelt runoff contribution to flow in the late spring months is projected to decrease.

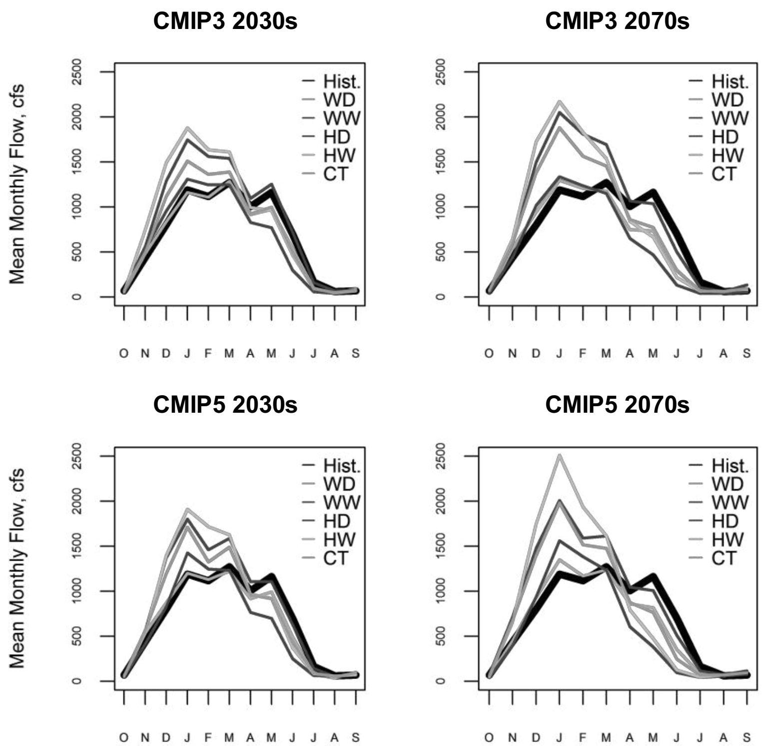


Figure 5-7. Historical and projected future mean monthly flow in the Scott River near Fort Jones (cfs)

5.4.1.7 Flow at Klamath River near Orleans

Historical and projected future mean monthly flows in the Klamath River near Orleans are presented in Figure 5-8. Managed flow in the Klamath River at Orleans reflects Upper Klamath Basin management and the contribution of tributary flows upstream of the Trinity River confluence. Historical mean monthly flows have a primary peak in March as a result of snowmelt runoff and a secondary peak in January as a result of winter rainfall. Projections of future conditions indicate increased peak flows for all scenarios, with the driest scenarios (HD and WD) similar in magnitude to historical. For the 2070s, a projected shift in the peak flow to earlier in the year corresponds with the reduced influence of snowmelt runoff as the climate warms and snowpack declines.

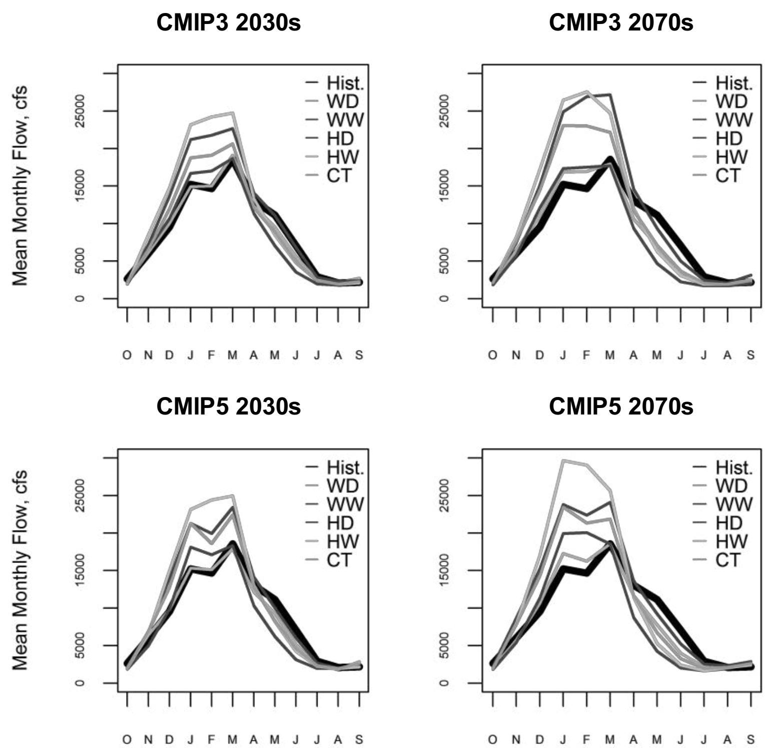


Figure 5-8. Historical and projected future mean monthly flow in the Klamath River near Orleans (cfs)

5.4.1.8 Flow at Klamath River near Klamath

Historical and projected future mean monthly flows in the Klamath River near Klamath are presented in Figure 5-9. Simulated flows in the Klamath River at Klamath integrate managed flows in all of the Klamath River Basin, including contributions from the Trinity River which are affected by Central Valley Project exports to the Sacramento River Basin. Historical mean monthly flows at this location exhibit a double peak in January and March corresponding with rainfall and snowmelt runoff, respectively. Projected changes in mean monthly flows for all but the driest climate change scenarios for the 2030s indicate a shift toward a more rain dominated basin, with peak flows occurring January. Interestingly, projected mean monthly flows at Orleans (Figure 5-8) do not show the same shift, corresponding with a greater increase in January flows in the Trinity River, whose confluence with the mainstem Klamath River is located between Orleans and Klamath. This may be due to the methods used to develop Trinity River flows; Trinity and Lewiston reservoirs were not explicitly modeled and instead adjusted outflows were used as input to RiverWare based on relationships between simulated natural flows (developed in Chapter 3) and historical gage records.

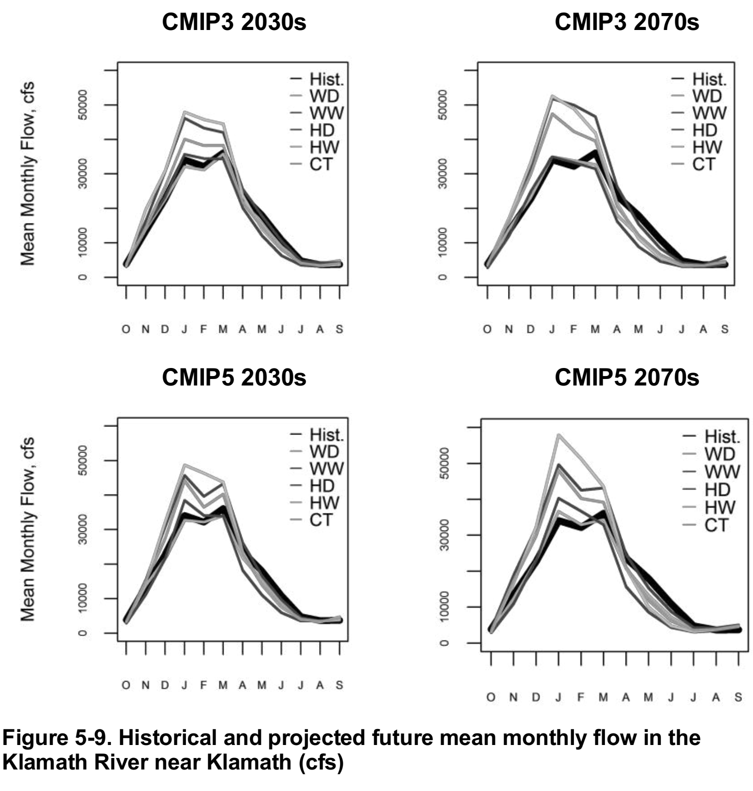


Figure 5-9. Historical and projected future mean monthly flow in the Klamath River near Klamath (cfs)

5.4.1.9 Klamath River Water Temperature

Historical and projected future mean monthly temperatures in the Klamath River near Klamath, as simulated by the RBM10 model, are presented in Figure 5-10. Historical water temperatures are at their maximum in August and at their minimum in January. Water temperature is projected to increase under all climate change scenarios considered by the study for both CMIP3- and CMIP5-based projections, and for both future time periods. Water temperatures historically are not favorable for salmon and projected increases in temperature exacerbate this issue.

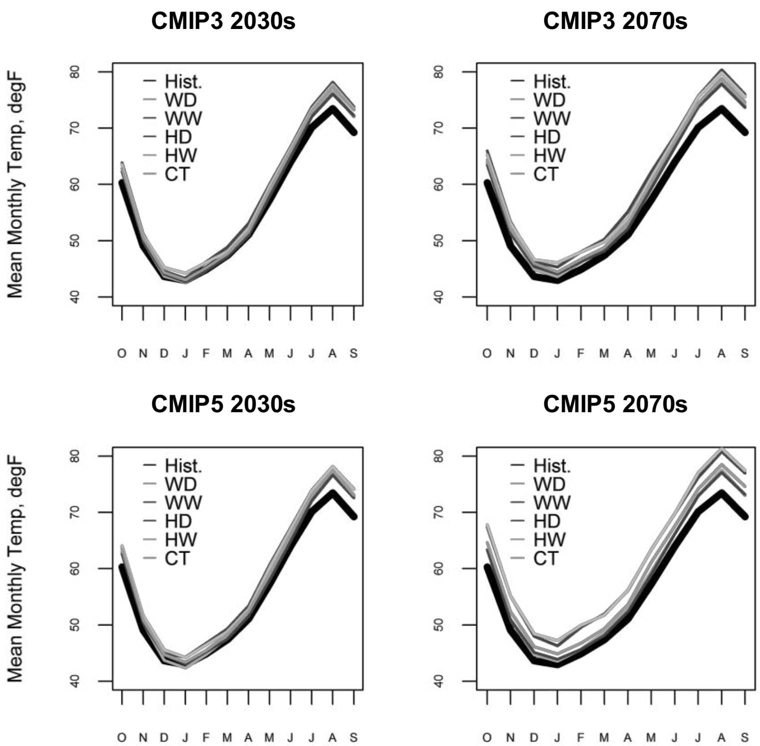


Figure 5-10. Historical and projected future mean monthly water temperature in the Klamath River (degrees F)

5.4.2 Analysis of Impacts – Ability to Deliver Water

To evaluate the ability of the Klamath River Basin to supply water to meet human needs, this study focuses on four measures: the percent of full irrigation water supply to the Klamath Project (from April through September), the mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow, mean annual flows in the Shasta River near Yreka, and mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Water supply measures under simulated historical conditions are provided in Table 5-6, while projected changes in these measures are illustrated in Figure 5-11. Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the simulation period, the sum of end-of February storage plus March–September inflows at Upper Klamath Lake (another indicator of total available supply from Upper Klamath Lake) was about 1.38 million acre-feet. Additional measures representing the total water supplies in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

> **Projected Klamath Project Supply**
>
> Klamath Project irrigation deliveries average about 93 percent of full supply under historical hydrology according to simulations by the Klamath Basin RiverWare Model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Table 5-6. Historical measures related to water supply.

Measure	Historical Value	Units
Mean Klamath Project supply	361.3	KAF
Mean annual UKL seasonal supply	1,378	KAF
Mean annual Shasta flow	187.7	cfs
Mean annual Scott flow	668.8	cfs

Notes: Changes are represented as percentages; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-11. Projected changes in water supply measures

In terms of the projected changes in water supply measures shown in Figure 5-11, projected changes in mean annual flow in the Scott and Shasta Rivers include increases for the wetter scenarios (WW and HW) close to about 20 percent for the 2030s and 30 percent for the 2070s and decreases for the drier scenarios (WD and HD) of less than 10 percent for the 2030s and 10 to 20 percent for the 2070s, with a central tendency scenario showing more modest increases than the wetter scenarios. For mean Upper Klamath Lake supply (end-of-February storage plus March-September inflow), again the wetter scenarios indicate projected increases, with greater increases for the 2070s, while drier scenarios indicate decreases. Similar results are shown for mean Klamath Project supply from April through

September. Percent change in Upper Klamath Lake supply and Klamath Project supply (the bottom two measures listed in Figure 5-11) is computed based on projected and historical simulated values under the 2013 BiOp management criteria. No consistent differences are apparent in comparing CMIP3- and CMIP5-based scenarios. However, together they provide comprehensive information on the projected range of changes in these water delivery measures. Table 5-6 summarizes the data behind Figure 5-11.

5.4.3 Analysis of Impacts – Hydroelectric Power

To evaluate historical conditions and impacts of climate change on hydroelectric power production, the study focuses on the following measures: mean annual hydropower production (summed over J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities); mean annual spill volumes at J.C. Boyle, COPCO 1, and Iron Gate dams; and mean spill days per year at the same three dams. Measures are computed using results from the Klamath Basin RiverWare model.

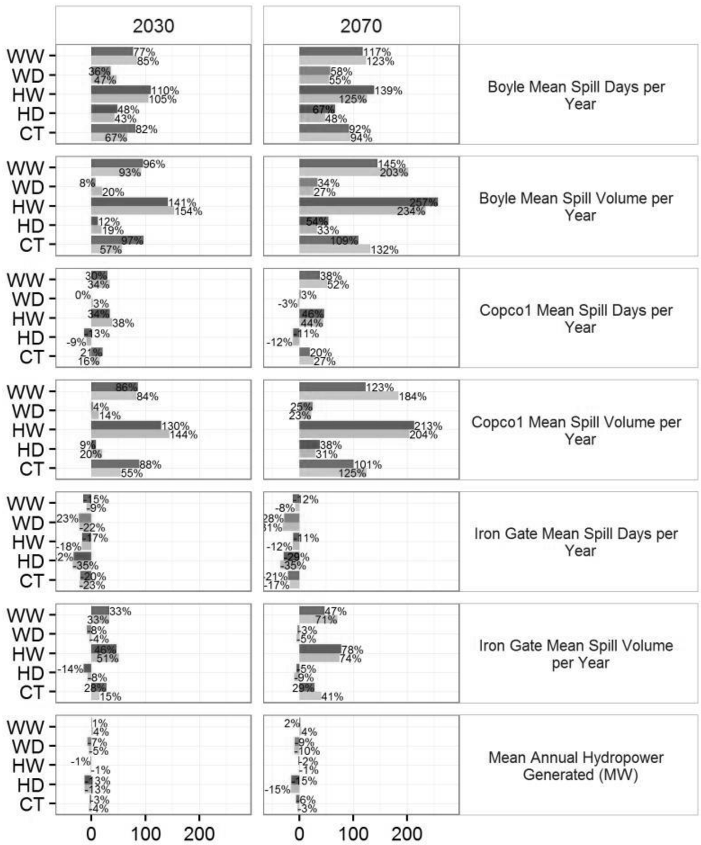
Historical hydropower measures are provided in Table 5-7, while projected changes in these measures are illustrated in Figure 5-12. Note that mean annual days with spill at the three facilities over the historical simulation period are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate.

Projected Hydropower Production

Hydropower production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. For all facilities, under almost all scenarios, frequency and volume of spill is likely to increase.

Table 5-7. Historical measures related to hydroelectric power

Measure	Historical Value	Units
Mean annual hydropower generated (MW)	26,741	MW
J.C. Boyle mean spill volume per year	163.0	KAF
COPCO 1 mean spill volume per year	186.4	KAF
Iron Gate mean spill volume per year	533.9	KAF
J.C. Boyle mean spill days per year	105.9	days
COPCO 1 mean spill days per year	42.8	days
Iron Gate mean spill days per year	170.3	days



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-12. Projected changes in hydropower measures

Figure 5-12 illustrates the percent change in identified hydroelectric power measures. Consistent with results discussed for basin-wide response variables, namely increased seasonal peak flows, the number of spill days and the mean annual spill volumes are projected to increase for most scenarios for both future time horizons. However, at Iron Gate the projected changes in spill volume are generally increasing, while the projected change in the mean number of spill days per year is less substantially decreasing. Projected mean number of spill days at J.C. Boyle and COPCO1 are generally increasing, while generally decreasing at Iron Gate. This result may be due to the fact that Iron Gate Reservoir has greater storage and is therefore better able to absorb high inflows than J.C. Boyle or

COPCO1. Also, the management criteria allow inclusion of a rule to avoid spill at Iron Gate, but not at J.C. Boyle or COPCO1, due in part to the need to meet environmental flow requirements.

Also, projected changes in mean annual hydropower production are much smaller on a percentage basis than the other measures, with the wetter scenarios indicating increases, the drier scenarios indicating decreases, and the central tendency scenario indicating minimal increases. Changes are between +4 percent and -13 percent for the 2030s and between +4 percent and -15 percent for the 2070s. Appendix D, Table D-12 summarizes the data behind Figure 5-12.

5.4.4 Analysis of Impacts – Recreation

Recreational measures in the Klamath River Basin are summarized for two main categories, fishing recreation and river boating recreation. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in select Klamath River reaches fall within the recommended range for each activity. Measures are computed using results from the Klamath Basin RiverWare model.

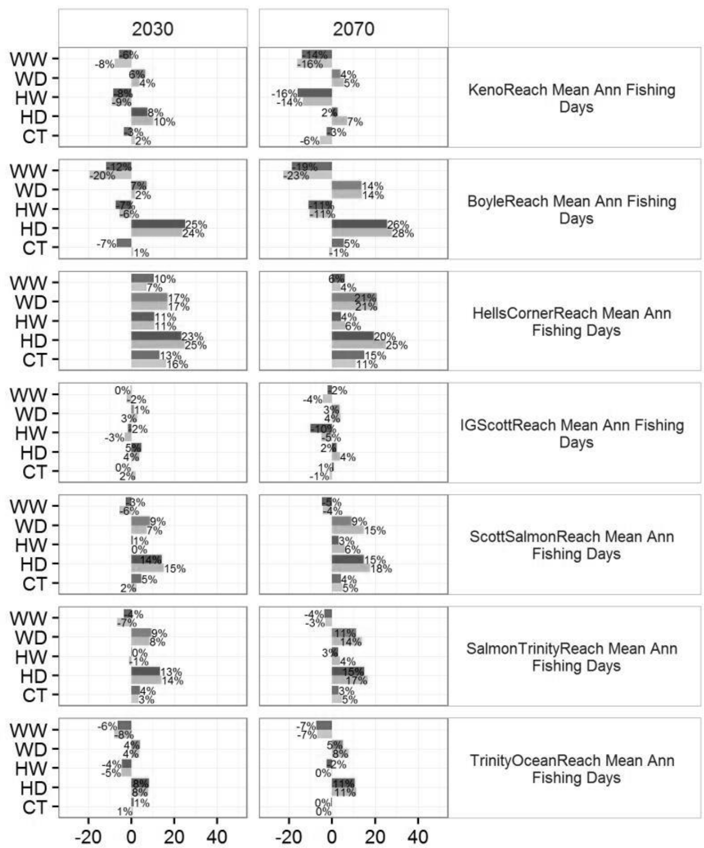
Recreation

The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Table 5-8 provides historical recreation measures for fishing and river boating, while projected changes in these measures are illustrated in Figure 5-13 (for fishing) and Figure 5-14 (for river boating). For the historical period, in general more days fall within the recommended range for fishing than for river boating.

Table 5-8. Historical measures related to fishing recreation

Measure	Historical Value	Units
Keno Reach mean annual fishing days	248	days
Boyle Reach mean annual fishing days	155	days
Hells Corner Reach mean annual fishing days	220	days
IG Scott Reach mean annual fishing days	275	days
Scott Salmon Reach mean annual fishing days	184	days
Salmon Trinity Reach mean annual fishing days	214	days
Trinity Ocean Reach mean annual fishing days	253	days
Keno Reach mean annual boating days	172	days
Boyle Reach mean annual boating days	59	days
Hells Corner Reach mean annual boating days	256	days
IG Scott Reach mean annual boating days	275	days
Scott Salmon Reach mean annual boating days	249	days
Salmon Trinity Reach mean annual boating days	214	days
Trinity Ocean Reach mean annual boating days	253	days



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-13. Projected changes in fishing recreation

For fishing recreation, the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios (WW and HW) indicate decreases in the number of fishing days for both future time horizons. Recommended flows for fishing are generally less than for boating, and overall projections of greater future flow volumes in the basin correspond with projected decreases in fishing days. The central tendency scenario indicates modest decreases in some reaches and modest increases in other reaches. Generally, the direction of change (increase or decrease) is consistent for both future time horizons within a given reach (except J.C. Boyle reach and Trinity Ocean reach). For some scenarios and measures, CMIP3-based projections indicate greater

change, while for others they may indicate smaller change. There is no consistency between CMIP3- and CMIP5-based projections in terms of projected change across scenarios or measures.

Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-14. Projected changes in river boating recreation measures

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. For instance, in the J.C. Boyle and Hells Corner reaches (from J.C. Boyle to COPCO 1) almost all scenarios indicate a decrease in the number of river boating days as a result of climate change, with the exception of the WW scenario for CMIP3 and the CT scenario for CMIP5. For the other reaches downstream of Iron Gate, the wetter

scenarios (WW and HW) generally indicate a reduction in the number of river boating days, while the drier scenarios (WD and HD) indicate increases in the number of river boating days (although not consistent for all measures). The CT scenario for those reaches below Iron Gate indicates modest changes (increases for most of those reaches). Note that the boating recreation measures do not account for the ability to release flows from J.C. Boyle to assure a suitable boating recreation flow range.

5.4.5 Analysis of Impacts – Ecological Resources

Measures related to ecological resources in the Klamath River Basin primarily concern fish and wildlife habitat and applicable species listed under ESA. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in the Scott and Shasta Rivers meet or exceed recommended flow thresholds for dry year conditions by McBain and Trush (2014). Note that the target flows were developed for the Shasta River and the same targets were applied to the Scott River, though the Scott River generally has greater flow volume. For this reason, the historical frequency of meeting flow targets in the Scott River is much higher than in the Shasta River. However, the dry year targets are not met 100 percent of the time in the Scott River.

Historical conditions and climate change impacts are also measured by computing watersupply to the Lower Klamath National Wildlife Refuge via Ady Canal. Measures are computed using results from the Klamath Basin RiverWare model.

> **Ecological Resources Impacts**
>
> The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. Also, a decrease in deliveries to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

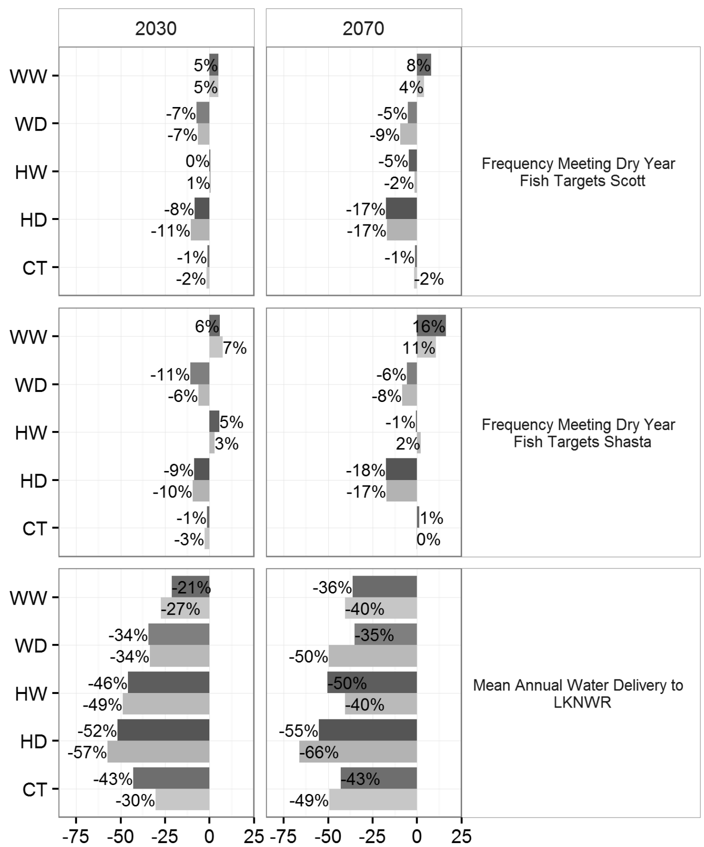
Historical measures relating to ecological benefits are provided in Table 5-9, while projected changes in these measures are illustrated in Figure 5-15. For the historical simulation period, neither dry year flow targets nor full demand at the LKNWR are met 100 percent of the time.

Table 5-9. Historical measures related to ecological resources

Measure	Historical Value	Units
Frequency meeting dry year fish targets Scott	70.5	Percent of days
Frequency meeting dry year fish targets Shasta	56.9	Percent of days
Mean annual water delivery to LKNWR	24.6	KAF

Projected changes in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers, represented as a percentage, indicate increases for

the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and HD), with greater change projected for the 2070s time horizon compared with the 2030s. CMIP3- and CMIP5-based projections are comparable, with one set of scenarios generally exhibiting more change (although not consistently one over the other). The CT scenario indicates a modest decrease in the frequency of ability to meet the dry year flow targets (i.e., negative change).



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-15. Projected changes in ecological resources measures

Figure 5-15, illustrating the percent change in the mean annual (water year) supply to the LKNWR, shows that for all climate change scenarios there is a decrease in supply to the LKNWR, more so for the 2070s compared with the

2030s future time horizon. CMIP3- and CMIP5-based scenarios are comparable, but do show some differences. For the 2030s CT scenario, the CMIP5-based scenario indicates a reduction of about 43 percent, compared to 30 percent for the CMIP3-based CT scenario. Note that model results indicate a decrease in deliveries to LKNWR for all scenarios, while they indicate projected increases or decreases in Klamath Project supply depending on the scenario. These results may in part be explained by a projected reduction in water supply from the Lost River. Also note that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Additionally, the LKNWR is not able to take advantage of spill water under these management criteria. The resulting effect of the management criteria and projected hydrologic changes is an overall reduction in LKNWR deliveries.

Frequency of meeting minimum recommended pool elevations in Clear Lake and Gerber Reservoir were also computed as performance measures for evaluating climate change impacts. These results are not illustrated, as minimum pool elevations are met or exceeded in all climate change scenarios considered by the Basin Study. Note that climate change scenarios represent adjusted historical climates that represent the statistics of future climate for two future time horizons, the 2030s and 2070s. Therefore, potential changes in the timing and frequency of drier years and wetter years are not represented. Potential future changes in drought or wet period frequency may affect the ability of operators to maintain minimum pool elevations in Gerber Reservoir and Clear Lake.

> **Water Quality Impacts**
>
> For historical hydrology conditions and all future climate scenarios, the MWAT falls within the "poor" classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

5.4.6 Analysis of Impacts – Water Quality

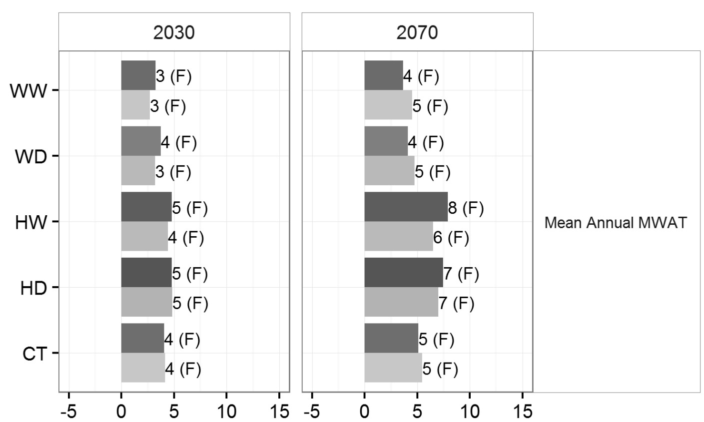
Water quality measures are presented in terms of meeting Klamath River temperature thresholds in the Klamath River near Klamath, California as recommended by the SONCC ESU salmon recovery plan (NMFS, 2012). Historical conditions and climate change impacts are evaluated by computing the mean across the simulation period of the MWAT at the Klamath River near Klamath and comparing values with those recommended in the salmon recovery plan. Analysis under historical hydrology showed that the MWAT fell within the "poor" classification for all years. Therefore, instead of reporting the frequency of the MWAT falling within the various categories ranging from "very good" to "poor," we instead report the computed MWAT and projected change in that value, as well as the degrees F by which the "poor" classification is exceeded. The "poor" classification threshold is 63.68 degrees F, or 17.6 degrees C.

Historical measures relating to water quality are provided in Table 5-10, while projected changes in these measures are illustrated in Figure 5-16. Historically the MWAT is computed as 75.7 degrees F, which is approximately 12 degrees higher than the "poor" classification threshold for the SONCC ESU coho salmon.

Table 5-10. Historical measures related to water quality.

Measure	Historical Value	Units
Mean annual MWAT	75.7	degrees F
Mean exceedance of MWAT – Poor	12.1	degrees F

Figure 5-16 shows that for all climate change scenarios the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s. Results indicate that the temperature regime in the Klamath River is likely to become more challenging for coho salmon under warmer future climate scenarios. Identified cold water refugia and groundwater springs will continue to be critical for the survival of the species in the Klamath River Basin.



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-16. Projected changes in mean annual maximum weekly average temperature

5.4.7 Analysis of Impacts – Flood Control

Flood control in the Klamath River Basin and projected changes due to a changing climate are evaluated for two types of measures: flood control releases from Upper Klamath Lake, and the date of seasonal peak flow at the major mainstem Klamath River dams (J.C. Boyle, COPCO 1, and Iron Gate). Flood control rules at Upper Klamath Lake are defined by the 2013 Proposed Action for Klamath Project Operations (Reclamation, 2012d). It is recognized that flood control measures exist for other reservoirs in the Klamath River Basin (e.g., Trinity River basin); however, due to the level of detail of the Klamath Basin RiverWare model, we focus on Upper Klamath Lake.

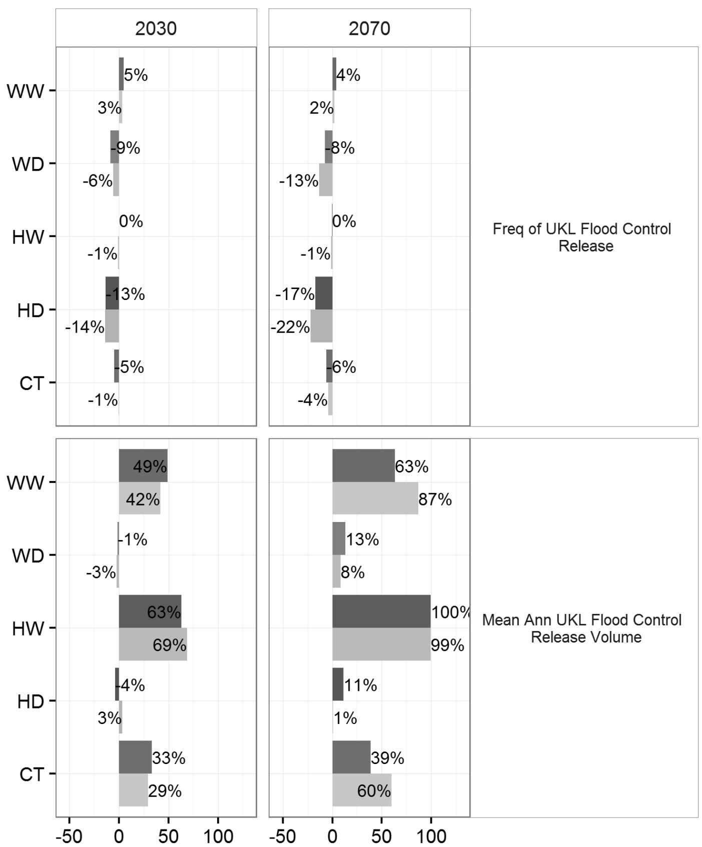
Flood Control Impacts

The frequency of Upper Klamath Lake flood control releases is projected to increase for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest increase. All scenarios project an increase in the mean annual flood control volume.

Historical recreation measures relating to flood control are provided in Table 5-11, while projected changes in these measures are illustrated in Figure 5-17. Under historical hydrology conditions, the frequency of flood control releases from Upper Klamath Lake is approximately 44 percent of days according to results from the Klamath Basin RiverWare model. The corresponding mean annual volume of flood control release water is approximately 224,000 acre-feet. Flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. The computations are consistent between the RiverWare model and the KBPM. However, it is acknowledged that the RiverWare model simulations generally indicate greater flows coming from the Lost River basin, thereby resulting in less demand by the Klamath Project for Upper Klamath Lake water, compared with the KBPM. This result may contribute to the seemingly high percentage of days of flood control release from Upper Klamath Lake. Greater flows from the Lost River basin may also explain some of the higher Keno Dam inflows in the winter time (refer to Figure 5-3). Future development of the model will further investigate these issues. The date of seasonal peak flow is the date of the center of mass of mean annual flow, or the average date by which half of the annual flow volume at the location has passed through. The historical seasonal peak flow at the three reservoirs mentioned ranges from early to mid-April.

Table 5-11. Historical measures related to flood control

Measure	Historical Value	Units
Frequency of UKL Flood Control Release	44.1	Percent of Days
Mean Ann UKL Flood Control Release Volume	224	KAF
Date of Seasonal Peak Flow at J.C. Boyle Reservoir	April 9	Date
Date of Seasonal Peak Flow at COPCO 1 Reservoir	April 17	Date
Date of Seasonal Peak Flow at Iron Gate Reservoir	April 15	Date



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-17. Projected changes in flood control measures

Figure 5-17 shows that the frequency of Upper Klamath Lake flood control releases is projected to increase or change minimally for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. Again, CMIP3- and CMIP5-based projections are generally consistent. Although there is a projected decrease in the frequency of flood control releases for several scenarios, the figure also shows that all scenarios show a projected increase in the mean annual flood control volume. Further, more water is being released in the future even though the occurrence of release may be decreasing. Minimal projected change in Upper Klamath Lake flood control release, along with projected increases in spill volumes at J.C. Boyle and COPCO1 (refer to Figure 5-12), may be explained by the different ways spill is accounted for at these locations. At Upper Klamath Lake, spill is considered the volume beyond that released for Klamath Project deliveries and environmental needs, whereas at the other locations it is more simply computed as the volume above which water can be released through the power facilities. Management criteria also play a role in the differing results.

The projected change in the date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate dams ranges from little or no change to a shift toward an earlier peak by as many as 17 days (HW scenarios for CMIP3 and CMIP5 for the 2070s future time horizon). For the 2030s, the CT scenario indicates a shift toward earlier in the year by up to one week at COPCO 1 and Iron Gate, while for the 2070s the projected change for the CT scenario is about 7 to 10 days earlier. In general, projected changes in the date of seasonal peak flow at J.C. Boyle are less substantial than at the other two locations evaluated, with projected changes having ranging from 1 to 4 days later for the 2030s, and 4 days earlier to 3 days later for the 2070s depending on the scenario. Table D-13 in Appendix D summarizes the results for all scenarios and time periods.

5.5 Summary of Findings

This chapter evaluates the ability of the basin to meet historical and projected future water needs using a framework of models and associated measures that are used to quantify vulnerabilities. Simulations (with historical and future hydrology conditions) were performed using existing operational constraints, mainly associated with the current Proposed Action for Klamath Project operations (Reclamation, 2012d), which dictate operations throughout the Upper Klamath Basin and have implications for the river from Link River Dam to its mouth.

Performance measures for selected categories provide a basis for assessing two things: first, the ability of the modeling framework to identify and evaluate vulnerabilities to meeting the basin's water needs, and second, the ability to evaluate the impacts of climate change on the watershed. The results provide useful insights as to how climate changes, without adaptation responses, impact the Klamath Basin. The following paragraphs summarize the above analysis of managed historical and projected future conditions.

Analysis of climate change impacts using the Klamath Basin RiverWare model and USGS RBM10 water temperature model show that mean EOM storage in Upper Klamath Lake will experience earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, EOM reservoir storage historically did not fluctuate substantially through the year. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase slightly. Projections of mean monthly managed flows at various locations throughout the study area indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

Figure 5-2 showing simulated historical and projected UKL storage helps to illustrate the projected change. The simulations show historical peak storage around May. Projections indicate a shift toward earlier peak storage. In addition, the simulations indicate more flood control release (any release above Project needs and environmental requirements) in the future as well. Although none of the figures illustrate UKL inflow, it appears that Project supply is projected to decrease slightly for the drier scenarios and increase slightly for the wetter scenarios, with a small increase for the central tendency scenario. Therefore, any reduction in summer UKL inflow does not appear to affect Project supply by a large amount, on average.

Historical hydrology enables an annual average of 93 percent of full delivery to Klamath Project irrigation, according to simulations by the Klamath Basin RiverWare model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Hydropower production summed for the J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities has historically been about 26,800 MW, according to RiverWare model simulations. Production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. We evaluated frequency and volume of spill at J.C. Boyle, COPCO 1, and Iron Gate dams and found that historically the dams spilled an average of 106 days at J.C. Boyle, 43 days at COPCO 1, and 170 days at Iron Gate per year. For all facilities, frequency and volume of spill is likely to increase with climate change.

Historical fishing and boating recreation in the Klamath River Basin has been strong (on the order of 155 to 275 fishing days per year and 59 to 275 river boating days per year). The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Using flow recommendations for a dry year in the Shasta River (defined as 61 to 100 percent exceedance) from McBain and Trush (2014), we found that flow

targets were met historically on an average of 57 percent of days in the Shasta River and 71 percent of days in the Scott River (which has about three times the mean annual flow of the Shasta River). The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. In the future, a decrease in water delivery to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

For historical conditions and all future scenarios, the MWAT falls within the "poor" classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

Finally, according to the Klamath Basin RiverWare model, the historical frequency of flood control releases from Upper Klamath Lake has been about 44 percent of days, with a mean volume of about 224,000 acre-feet. The frequency of these releases is projected to increase or show little change for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. All scenarios project an increase in the mean annual flood control volume. The date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate has historically been early to mid-July, according to the model simulations. Projections of future conditions show a general shift of this peak toward earlier in the year, although the degree to which this is the case varies by scenario and location. The most modest changes are projected for J.C. Boyle (on the order of 4 days later to 3 days earlier for the 2070s). Greater shifts are projected for COPCO 1 and Iron Gate, on the order of 1 day later to 9 days earlier for the 2030s and 2 to 16 days earlier for the 2070s.

Results of the system risk and reliability analysis support the common understanding that the Klamath River Basin has experienced difficulties in meeting the range of water needs. Projected increases in precipitation and flow volumes at many locations in the basin may reduce water supply gaps in some ways; however, greater challenges are projected for ecological resources such as fish and wildlife, as well as irrigators in the Upper Klamath Basin.

5.6 Uncertainties Associated with System Reliability Analysis

This section summarizes uncertainties associated with various aspects of the Klamath River Basin Study system risk and reliability analysis. The uncertainties primarily correspond to the modeling used to evaluate historical and future conditions. The modeling framework for this analysis includes development and implementation of the Klamath Basin RiverWare model, as well as implementation of the USGS RBM10 water temperature model for the mainstem Klamath River. Uncertainties associated with each of these modeling efforts are

identified and described below. Further discussion of uncertainties associated with the Klamath Basin RiverWare model will be presented as part of a separate technical report documenting the development of the model.

The Klamath Basin RiverWare model was developed as a basin-wide tool for simulating current operations under the 2012 Proposed Action for Klamath Project operations (Reclamation, 2012d). Operating rules for the Proposed Action were translated from the original modeling platform of the Klamath Basin Planning Model into RiverWare. Because the KBPM modeling platform differs from the RiverWare platform, management rules in some instances were modified to accommodate the RiverWare platform. Calibration of the RiverWare model, using historical data consistent with KBPM data, was performed to the best of our ability. However, differences persist between historical hydrology-driven model simulations using the KBPM and the RiverWare models. Model calibration will continue to be addressed in the future as the model is applied to future projects.

The USGS RBM10 water temperature model was used in its original form as part of the Basin Study. Historical inputs consistent with the Basin Study water supply and demand assessments were used as input to the RBM10 model to maintain consistency within the Basin Study. Many of these inputs differed from those used in the original implementation of the RBM10 model for the dam removal studies. As such, we employed a bias correction technique for the meteorological data so it better represented the statistics of the original model data. This also facilitated use of the model in the Basin Study because, under this methodology, it was not necessary to recalibrate parameters of the water temperature model.

Simulated managed streamflows at boundary locations used by the RBM10 model were provided by the Klamath Basin RiverWare model. Original development of the RBM10 model used USGS gage data for these boundary inputs. Historical simulated RiverWare model output was, as expected, different from the inputs for the original model. Within the RiverWare model, it was possible to experience negative or close to negative flows in certain river reaches due to river routing and the computation of reach gains. The RBM10 model cannot compute water temperature provided negative river flows, so a 5 cfs adjustment was made to simulated boundary flow for those timesteps where negative flows occurred.

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Chapter 6
Klamath River Basin Study
Evaluation of System Reliability with Strategies

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Chapter 6 Evaluation of System Reliability with Strategies

6.1 Introduction

Chapter 6 presents the process that was developed and utilized to formulate and screen adaptation strategies for reducing identified gaps between water supply and demand. It also identifies the strategies carried forward for quantitative evaluation under the framework developed for the Basin Study, which is further described in Chapter 5, System Risk and Reliability Analysis. Figure 6-1 provides an overall schematic of the Basin Study approach.

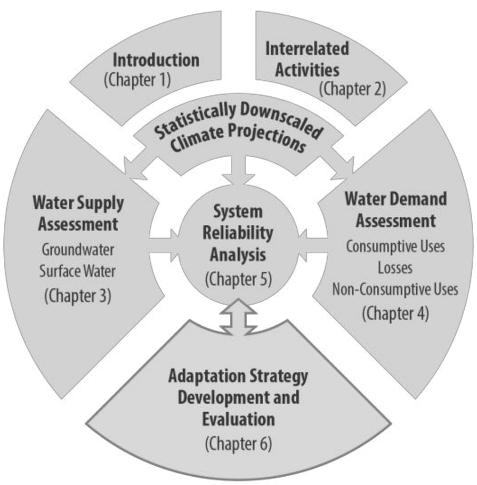


Figure 6-1. Overall approach of Klamath River Basin Study, highlighting Chapter 6

6.2 Formulation of Adaptation Strategies

The overall approach for formulating adaptation strategies to be evaluated in the Klamath River Basin Study includes the following steps:

- Identify strategies that cover a range of options.
- Organize proposed strategies in general categories based on their primary function.
- Characterize strategies based on a set of criteria to facilitate strategy screening.
- Develop representative options that allow for simplified analysis and that avoid redundancy.

Each of these approach steps is further described below.

6.2.1 Approach to Adaptation Strategy Identification

Adaptation strategies were identified through a comprehensive literature review of studies on climate change and water supply issues specific to the Klamath River Basin as well as studies focused on the broader Pacific Northwest. In addition to this literature review, the Basin Study team completed outreach to Klamath River Basin agency representatives, tribal representatives, stakeholders, and residents through conference calls, attendance at water supply management and planning meetings in the basin, and outreach through the Basin Study website.

The literature review effort identified 49 reports, studies, agreements, doctoral dissertations, and masters' theses completed by federal and state resource agencies, tribal natural resource departments, and university researchers. From this literature review and stakeholder input, 185 unique adaptation strategies were identified and carried forward for evaluation in the screening process described below. The full list of identified adaptation strategies is presented in Appendix E.

6.2.1.1 Organization of Proposed Adaptation Strategies

The adaptation strategies were divided into categories to facilitate a comparison of the strategies with similar approaches to addressing water supply and demand changes. These categories – increase supply, decrease demand, modify operations, and governance and implementation – are each populated with multiple strategies. This same general approach was used for the Colorado River Basin Water Supply and Demand Study (Reclamation, 2001e). The four general categories are further described below:

> ***Increase Supply:*** This category encompasses strategies that result in an anticipated increase in water supply or that identify alternative water supplies. Strategy examples include creating groundwater recharge

opportunities, increasing surface storage capacity, increasing the use of recycled water, developing conjunctive use programs, and implementing vegetation management actions.

Decrease Demand: This category encompasses strategies that result in an anticipated decrease in water demand either directly or indirectly. Strategy examples include M&I water conservation (direct reduction), agricultural water conservation (direct reduction), energy water use efficiency (indirect reduction), and reductions in environmental demand (direct reduction).

Modify Operations: This category encompasses strategies that involve alternative management decisions that may result in a change in water supply and/or demand. Strategy examples include improving infrastructure reliability and efficiency, reducing hillslope and/or bank erosion, improving water quality, improving preparedness for extreme events, reducing reservoir and lake evaporation, reducing out of basin transfers, improving intra-regional water transfers, or improving operational flexibility.

Governance and Implementation: This category encompasses strategies that involve changes in policy, management, legal structure, or future governance issues in the Klamath River Basin. Strategy examples include improvements to public education, developing and improving partnerships between stakeholders, improving research, modifying or developing new policies, developing decision support tools, providing for habitat protection, seeking funding, implementing watershed management, and improved land use practices.

Figure 6-2 indicates the number of proposed adaptation strategies identified per category.

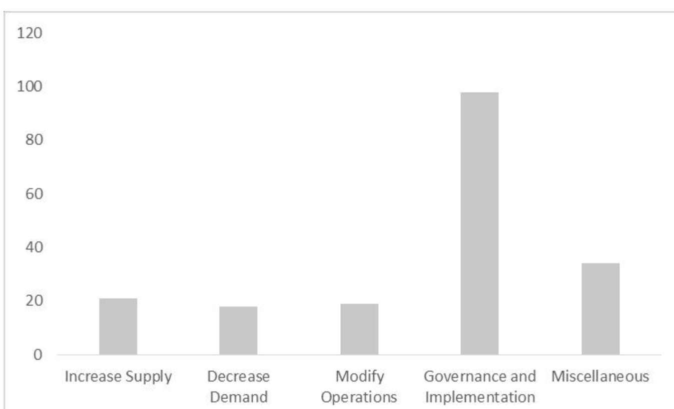


Figure 6-2. Number of adaptation strategies identified

6.2.1.2 Criteria for Adaptation Strategy Screening

Once the proposed strategies were organized into general function categories, they were evaluated and screened in a staged analysis effort. Evaluation measures were utilized to assess each adaptation strategy's capacity to address changes in water supply and demand. These evaluation measures were developed by Reclamation in consultation with the non-federal partners consistent with the selection criteria developed for the evaluation of options during development of the On Project Plan (Klamath Water and Power Agency, 2013). The On Project Plan screening criteria were formulated through an extensive stakeholder outreach process that resulted in wide acceptance of their use for the screening of the water conservation and efficiency, water storage, groundwater development and substitution, and demand management options identified in that planning effort. Reclamation and the non-federal partners relied on these widely accepted criteria during the development of evaluation measures for the Basin Study to incorporate the input already provided by these stakeholders.

The initial screening effort evaluated each strategy in each category to determine if it could be represented by the Basin Study models. Strategies that could be modeled could be quantitatively evaluated in this Basin Study Report; strategies that could not be modeled were evaluated qualitatively. The results of the first screening for each strategy are included in Appendix E.

Following the initial screening, the strategies that could be modeled were evaluated qualitatively, utilizing the criteria detailed below in Table 6-1, to assess the strategy's implementation risk and uncertainty, reliability, and environmental effect. Reclamation and the non-federal partners qualitatively evaluated these screening criteria, arriving at representative strategies that encompass the collective goals of the criteria, present the greatest potential for beneficial effect, and were identified as high priorities to the non-federal partners, while also involving a range of options for reducing identified vulnerabilities in the Klamath River Basin.

Table 6-1. Description of criteria for assessing adaptation strategies

Provides verifiable, durable and implementable benefit to align water supply and demand for the Klamath River Basin
This criterion evaluates whether a strategy is capable of providing verifiable and affordable reductions in projected water supply/demand gaps and assures all associated administrative requirements are reasonable and not overly burdensome or complex. Strategies performing well under this criterion are expected to provide a measurable water supply increase, and strategies with low ratings are anticipated to deliver minimal increases in water supply that would be difficult to verify.
Consistency with legal and regulatory requirements
This criterion evaluates whether a strategy is implementable with respect to compliance with all existing laws, regulations, or contracts, or requires a relatively minor revision in such requirements that would allow for implementation. Strategies that performed well under this criterion had no identified legal and regulatory issues and strategies with low ratings would require major legal or regulatory actions, like new water rights and major environmental compliance investigations.

Table 6-1. Description of criteria for assessing adaptation strategies

Affordability
This criterion evaluates whether a strategy furthers the objective of aligning demand with Klamath water supply availability in a manner that is commensurate with the cost, allowing for a comparison of the relative cost of alternative strategies. This criterion was rated with high ranking strategies requiring no new costs or investment and low performing strategies requiring large capital expenditures and/or high long-term operations and maintenance costs.
Flexibility
This criterion evaluates whether a strategy would have, or not unduly limit, the capability to be adjustable over time. This criterion was rated with high ranking strategies allowing for implementation to be adjusted over time and low ranking strategies implementing new infrastructure that could not be moved or have its operations modified.
Protection of water rights
This criterion evaluates whether a strategy would result in injury to existing water rights holders. This criterion was rated with high ranking strategies producing no effect on existing water rights and low ranking strategies potentially impacting neighboring surface and groundwater availability.
Environmental and third-party impacts and benefits
This criterion evaluates whether a strategy would comply with applicable environmental laws and not involve unacceptable environmental impacts. This criterion was rated with high ranking strategies producing no effect on environmental resources and low ranking strategies generating adverse impacts on water quality and other resources.

6.2.1.3 Summary of Selected Adaptation Strategies

The adaptation strategy screening process resulted in the identification of five strategy concepts that are carried forward for evaluation in the Basin Study models. This section summarizes these strategy concepts by category.

Increase Supply

Additional Surface Water Storage Capacity

This strategy concept includes quantification of potential surface storage opportunities in the Upper Klamath Basin. Some examples of proposals that fall within this strategy concept are listed in Appendix E. Additional surface water storage capacity is quantified as the incremental excess water defined in the Klamath Basin Planning Model. This excess water is quantified as the remaining water after releases are made to the Klamath Project and to meet environmental needs, including instream flow needs in the Klamath River and water stored in Upper Klamath Lake to maintain elevations. For this strategy, it is assumed that the remaining water could be stored for future use; however, it is acknowledged that the 2013 Klamath Project proposed action Biological Assessment and associated Biological Opinion consider this quantity to be part of the environmental water account.

Decrease Demand

Agricultural Water Conservation

This strategy concept includes reduction in overall agricultural water demand throughout the basin by a range of percentages (between 30 percent and 50 percent). One goal of this implemented strategy concept is to determine how

much reduced agricultural demand would be needed to offset the impacts of climate change alone. Reductions in agricultural water demand might be obtained through means identified in the proposed strategy examples listed in Appendix E. These might include canal lining and pump operation optimization; crop idling, irrigated land retirement and rain-fed agriculture; shifting agricultural production to more drought tolerant crops; and converting irrigation systems to more efficient technologies along with the use of cover crops to improve soil productivity.

Additional Supply to Upper Klamath Lake
This strategy concept captures the additional 30,000 acre-feet of water provided for Upper Klamath Lake in the KHSA, KBRA, and Upper Klamath Basin Comprehensive Agreement as generated by land retirement actions in the Upper Klamath Basin. The strategy concept does not identify individual areas where water demand reduction would occur. However, this strategy assumes that the additional volume of water is made available proportionally between the Sprague River, the Williamson River upstream of its confluence with the Sprague River, and the local inflows between the confluence and Upper Klamath Lake. The proportions of the total 30,000 acre-foot volume are determined based on the relative contributions to Upper Klamath Lake inflows of mean annual flow from these three sources (Sprague River, Williamson River, and local inflows between the Sprague-Williamson confluence and Upper Klamath Lake). The goal of this strategy concept is to evaluate the effect of reductions in collective water use upstream of Upper Klamath Lake. This strategy also assumes that operating rules are not modified to compensate for the additional Upper Klamath Lake inflow.

Modify Operations
Two strategy concept options were developed to capture the adaptation strategy articulated in the screening process as “reduce environmental demand.” These strategy concepts were developed to facilitate the analysis in the Basin Study models of five strategy examples: protect cool water refugia; keep higher quality water in-stream to protect species and river ecosystems by using lower quality water for agricultural purposes; purchase water from water-rights holders and keep that flow in-stream to reduce demand on a short-term basis; curb demand with ecosystem restoration/improvements, water use effectiveness, and environmental water scarcity programs; and ensure adequate flows for fish and wildlife habitat.

Tributary Water Temperature Reduction
This strategy concept addresses the need for cold water refugia in summer months to support fish and wildlife, particularly salmonids, in the Klamath River Basin tributaries. This concept is based on existing emergency water management planning in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs. In this strategy concept, a 4 degrees Celsius (degrees C) reduction in water temperature (or about 7 degrees F) in the Scott and Shasta Rivers is assumed as input to the RBM10 stream temperature model for the Klamath River, and effects of that reduction on mainstem Klamath River temperature are evaluated.

6.2.1.4 Sensitivity of Simulated Water Temperature to Changes in Flow and Climate

This strategy concept includes exploring relationships between water temperature change and streamflow change, using historical and future climate change simulations of managed streamflow (using the Klamath RiverWare planning model) and river temperature (using the RBM10 model). By evaluating potential relationships between temperature and flow change, it may be possible to estimate the needed change in flow to obtain a desired change in Klamath River temperature. Such information may be valuable in determining what changes in water management may be needed to counter the impacts of climate change.

6.3 Uncertainties Associated with Strategy Selection

Adaptation strategies were intended to encompass a range of management actions. They were selected to be broad in scope with basin-wide implications, and not specific to any particular subbasin or singular project operation. Broad strategy concepts were selected, in part because numerous existing studies have evaluated some proposed actions in depth, and also because management conditions in the basin are dynamic. Strategies were selected with the intent that they noticeably reduce water supply and demand imbalances; however, they were selected without prior knowledge of their relative impact. Therefore, there is uncertainty as to whether the selected strategies have greater impact on system reliability than those that were not selected. In short, there may be additional strategies that could reduce water supply and demand imbalances but were not considered by the study.

In addition, strategies were initially screened on their ability to be modeled in the framework of the Basin Study. A strategy that could not be modeled by the Basin Study framework may in fact have substantial impact on system reliability; however, the impact could not be appropriately assessed with respect to that resulting from selected strategies.

6.4 Evaluation of System Reliability with Adaptation Strategies

In Chapter 5, projected response to climate change is evaluated by examining effects on basin-wide response measures and on several categories of performance measures. Basin-wide response measures include flows at key locations, river temperature, UKL storage, and Project delivery. Performance measures provide additional details on operational elements such as hydropower, flood control, recreation, and ecological resources. In the analysis described in Chapter 6, the potential for adaptation strategies to affect response to climate change is evaluated. Basin-wide response measures and system performance measures are examined, comparing the collective effects of both climate change and adaptation strategies to the effects of climate change alone.

An illustration of the model scenarios that capture these differences is visualized in Figure 6-3. The baseline scenario uses historical hydrology, and in Chapter 5 we compare results from model simulations using five future climate scenarios, for both the 2030 time horizon and the 2070 time horizon, as well as CMIP3- and CMIP5-based temperature and precipitation projections. The blue line in Figure 6-3 demonstrates this comparison. In this chapter (Chapter 6), the focus is on the effects depicted by the orange line and how these differ from the baseline comparison.

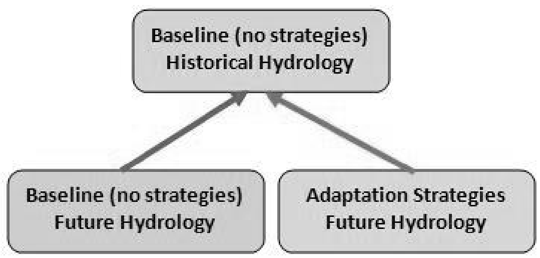


Figure 6-3. Illustration of methodology for evaluating adaptation strategy concepts

The following sections summarize projected changes in basin-wide response variables and system performance measures according to the baseline (i.e., with climate change scenarios but no adaptation strategy concepts) and adaptation strategy concepts previously discussed. Summary figures throughout this section illustrate changes in the strategy concepts associated with agricultural water conservation and additional supply to Upper Klamath Lake. The strategy concepts are defined as follows in the summary figures:

> **Baseline** – with climate change impacts, but no adaptation strategy concepts. This is similar in concept to a no action scenario.
>
> **Reduce ET 30% -** Reduction of agricultural demands throughout the basin by 30 percent
>
> **Reduce ET 50% -** Reduction of agricultural demands throughout the basin by 50 percent
>
> **Add 30KAF** – Addition of 30 KAF annually to Upper Klamath Lake inflow (contributed proportionally by Williamson River, Sprague River, and other gains, based on mean annual flow)

Results for additional strategy concepts are summarized for water quality measures. These additional strategy concepts are defined as follows in the summary figures under Section 6.4.6, Analysis of Impacts – Water Quality. Note

that this adaptation strategy concept only affects the water quality measures. Therefore, results for this measure are only summarized for these measures.

Reduce Shasta Scott 4degC – Reduction of Shasta and Scott River temperatures by 4 degrees C (about 7 degrees F) year round

Add Flow 10% - Addition of flow by 10 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

Add Flow 20% - Addition of flow by 20 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

Reduce Tribs 4degC - Reduction of temperatures by 4 degrees C (about 7 degrees F) year round in all tributaries represented in the RBM10 water temperature model. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

Reduce Dam Outflow 4degC - Reduction of temperatures by 4 degrees C (about 7 degrees F) year round from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

Results for the strategy concept to quantify additional surface water storage capacity are summarized under Section 6.4.7, Analysis of Impacts – Flood Control, where the mean annual Upper Klamath Lake flood control volume is quantified and evaluated. This strategy concept does not identify any specific location for additional surface water storage; however, the location for quantifying additional water is at Upper Klamath Lake.

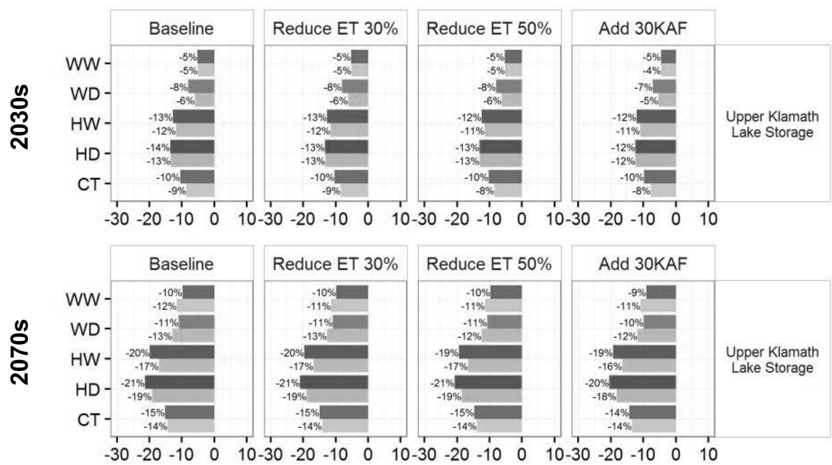
6.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of system reliability under baseline and scenarios with adaptation strategy concepts allows for an understanding of how strategies may reduce the basin's vulnerability to climate change. Similar to Chapter 5, we explore projected change in managed river flow at various locations within the basin, as well as mainstem Klamath River stream temperature.

6.4.1.1 Upper Klamath Lake Storage

Projected changes in mean annual end of month (EOM) storage in Upper Klamath Lake under baseline and strategy scenarios are summarized in Figure 6-4. Under the baseline scenario (climate change only), mean annual storage is projected to decline under all scenarios, more so for the 2070s than for the 2030s. Neither of the strategy concepts for reducing agricultural water demand (by 30 percent and 50 percent) reduce climate change impacts substantially. Percent reductions in storage conditions are minimally affected, except for the HD climate change scenario for the 2030s and for the warmer scenarios (WW and WD) for the 2070s.

Adding 30 KAF of inflow to Upper Klamath Lake does reduce the impacts of climate change by 1 to 2 percent under all climate change scenarios for both the 2030s and 2070s. Table 6-2 summarizes projected changes in storage volume under the CT scenario for both future time periods. Implementing the Add 30KAF strategy concept results in a 26 or 33 KAF reduction in mean annual storage for the 2030s, compared to 29 or 35 KAF for the baseline for CMIP3- and CMIP5-based projections, respectively. For the 2070s, the projected reduction is 46 or 48 KAF, compared to 48 or 51 KAF for the baseline.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

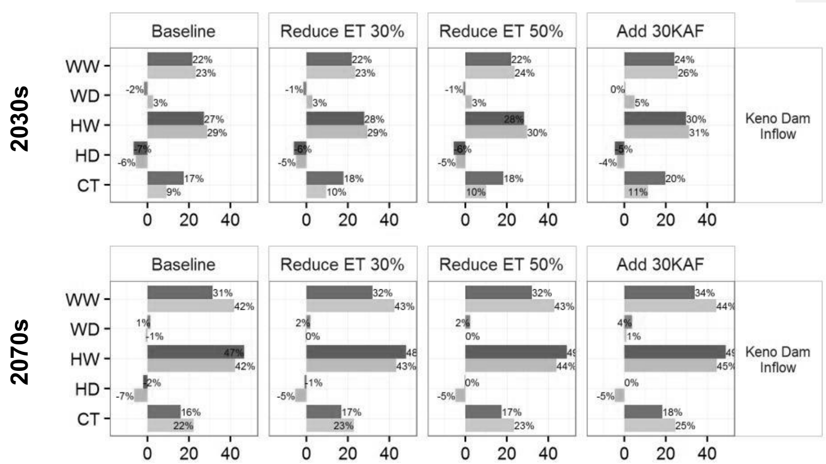
Figure 6-4. Projected change (percent) in mean annual Upper Klamath Lake storage

Table 6-2. Summary of projected change in mean annual Upper Klamath Lake Storage for the Central Tendency scenario in units of KAF

Central Tendency Scenario	CMIP	Baseline (KAF)	Reduce ET 30% (KAF)	Reduce ET 50% (KAF)	Add 30KAF (KAF)
Historical		337			
2030	CMIP3	-29	-29	-28	-26
	CMIP5	-35	-35	-34	-33
2070	CMIP3	-48	-47	-47	-46
	CMIP5	-51	-50	-50	-48

6.4.1.2 Keno Dam Inflow

Projected changes in mean annual inflow to Keno Dam under baseline and strategy scenarios are summarized in Figure 6-5. Under the baseline scenario (climate change only), mean annual inflow is projected to increase under the wetter scenarios (WW and HW) for both future time periods and decrease modestly under the drier scenarios (WD and HD), with an increase under the CT scenario projected to be 9 or 17 percent for the 2030s and 16 or 22 percent for the 2070s, depending on consideration of CMIP3- or CMIP5-based projections. Implementation of each of the strategy concepts would maintain or increase the mean annual inflow at Keno, and by similar percentages. Addition of 30 KAF of inflow to Upper Klamath Lake appears to have a larger effect on Keno inflow than does reduction in agricultural demands in the regions upstream of Keno.



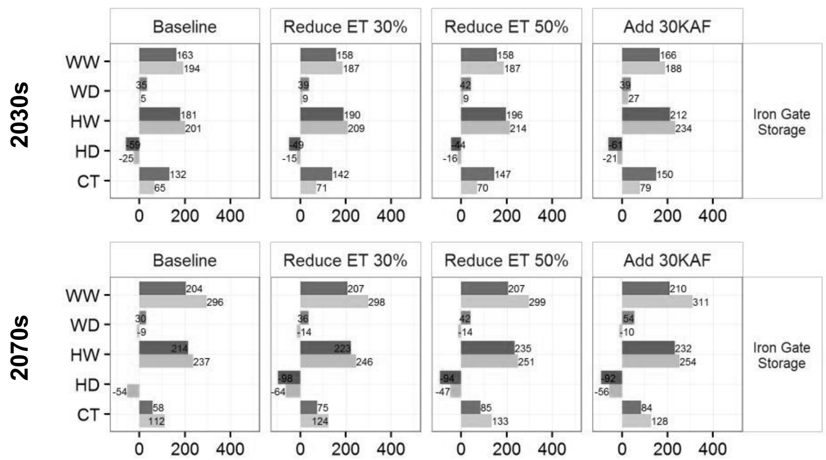
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-5. Projected change (percent) in mean annual inflow to Keno Dam

6.4.1.3 Iron Gate Reservoir Storage

Projected changes in mean annual Iron Gate Reservoir storage under baseline and strategy scenarios are summarized in Figure 6-6. Under the baseline scenario (climate change only), mean annual storage is projected to change very little on a percentage basis compared with the historical simulation. Iron Gate Reservoir elevations have not fluctuated much historically, typically staying between 55,000 acre-feet and 57,000 acre-feet. Projected changes shown in Figure 6-6 are reported in units of acre-feet. Mean annual storage is projected to increase under all scenarios and strategies, with the exception of the HD scenario for both the 2030s and 2070s time periods. Reduction of agricultural demand provides some additional storage at Iron Gate, but generally the addition of 30 KAF inflow to Upper Klamath Lake has a larger impact on Iron Gate storage. Still, all

adaptation strategy concepts do not substantially change Iron Gate storage and do not generally counter the effects of climate change.

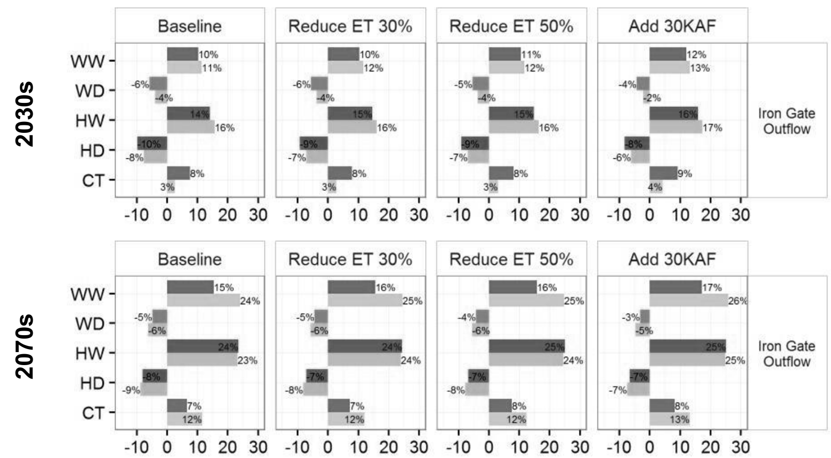


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-6. Projected change (acre-feet) in mean annual Iron Gate Reservoir storage

6.4.1.4 Iron Gate Reservoir Outflow

Projected changes in mean annual Iron Gate Reservoir outflow under baseline and strategy scenarios are summarized in Figure 6-7. Under the baseline scenario (climate change only), mean annual outflow is projected to increase under wetter scenarios (WW and HW) and decrease modestly under drier scenarios (WD and HD), with the CT scenario indicating increases of 3 or 8 percent for the 2030s and 7 or 12 percent for the 2070s. Implementation of adaptation strategies does not substantially counter climate change impacts. Reduction of agricultural demand increases the effect of additional outflow at Iron Gate, but only by about one percent for most climate change scenarios considered. Additional inflow to Upper Klamath Lake (Add 30KAF) increases the additional outflow at Iron Gate by up to 2 percent over the baseline response to climate change alone.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-7. Projected change (percent) in mean annual inflow to Iron Gate Reservoir.

6.4.1.5 Shasta River Flow

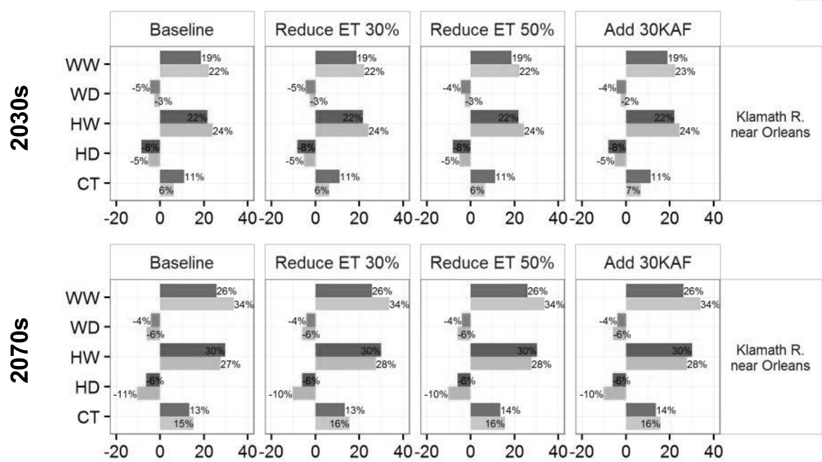
Projected changes in mean annual flow in the Shasta River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

6.4.1.6 Scott River Flow

Projected changes in mean annual flow in the Scott River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

6.4.1.7 Flow at Klamath River near Orleans

Projected change in mean annual flows in the Klamath River near Orleans under baseline and strategy scenarios is summarized in Figure 6-8. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 6 or 11 percent for the 2030s and 13 or 15 percent for the 2070s, according to model simulations. Similar to other upstream locations, reduction of agricultural demand in the contributing area to the basin upstream of Orleans results in no change for the 2030s and little change for the 2070s in simulated managed flow on a percentage basis. Additional Upper Klamath Lake inflow of 30 KAF annually has only a slightly greater impact than agricultural demand reduction.

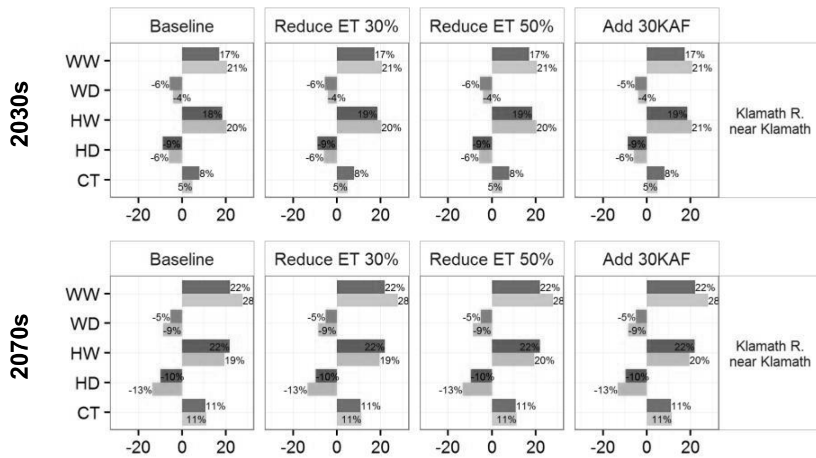


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-8. Projected change (percent) in mean annual flow at Klamath River near Orleans

6.4.1.8 Flow at Klamath River near Klamath

Projected changes in mean annual flows in the Klamath River near Klamath under baseline and strategy scenarios are summarized in Figure 6-9. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 5 or 8 percent for the 2030s and 11 percent for the 2070s, according to model simulations. Generally, the adaptation strategies either have no influence or increase flows on a mean annual basis, about one percent or less for the 2030s and no noticeable change for the 2070s. This result is in part due to the fact that any change in flow volume is a small percentage of the overall river flow at Klamath, which is close to the mouth of the basin.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-9. Projected change (percent) in mean annual flow at Klamath River near Klamath

6.4.2 Analysis of Impacts – Ability to Deliver Water

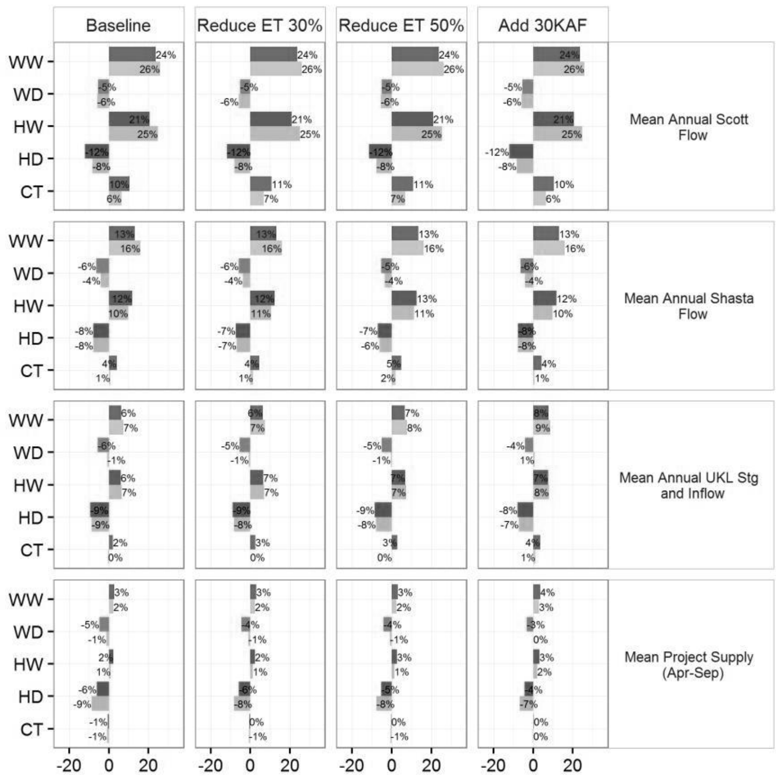
As discussed in Chapter 5, measures of the ability of the Klamath River Basin to supply water to meet human needs include (1) the April through September irrigation water supply to the Klamath Project (Project Supply), (2) mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow (Upper Klamath Lake Supply), (3) mean annual flows in the Shasta River near Yreka, and (4) mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the historical simulation period, the Upper Klamath Lake Supply parameter was about 1.38 million acre-feet. Additional measures representing the overall hydrology conditions in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

Projected changes in water supply measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-10 and for the 2070s in Figure 6-11. For the Scott and Shasta Rivers under the baseline scenario (climate change only), mean annual flow is projected to increase under wetter scenarios (WW and HW) and decrease under drier scenarios (WD and HD), with the CT scenario indicating a modest increase. For all scenarios, projected changes are greater for the 2070s time period than for the 2030s. For both rivers, reduction of agricultural demand (by 30 or 50 percent) does not appear to provide a substantial amount of additional flow volume, as indicated by no change or small change in the percent increase or decrease of mean annual flow. As expected, additional 30 KAF of inflow to Upper Klamath Lake does not impact mean annual flow in these rivers.

Projected Klamath Project Supply

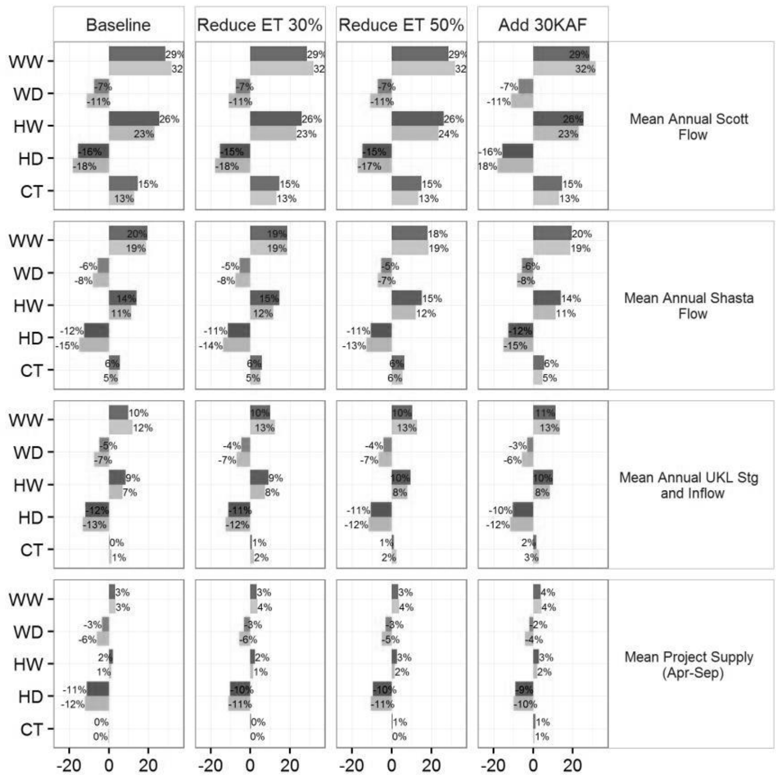
Neither reduction of agricultural demands nor additional 30 KAF inflow to Upper Klamath Lake have substantial impacts on mean Klamath Project water supply (April – September). However, the additional 30 KAF inflow does provides slightly greater additional supply than a reduction in agricultural demands.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-10. Projected change in water supply measures for the 2030s with strategies in place, expressed as percent change

For the Upper Klamath Lake Supply measure, adaptation strategy concepts either result in no change or result in small increases in this value, thereby adding to increases in the measure for those climate change scenarios where there are increases (generally wetter scenarios), or decreasing the reduction for other scenarios (generally drier scenarios). Similarly, reduction of agricultural demands and additional inflow to Upper Klamath Lake do not have substantial impacts on mean April through September Klamath Project water supply. However, an additional 30 KAF provides greater additional supply than a reduction in agricultural demands, as indicated by greater increases in supply for the wetter scenarios and small decreases for the drier scenarios, compared with the historical simulation.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-11. Projected change in water supply measures for the 2070s with strategies in place, expressed as percent change

6.4.3 Analysis of Impacts – Hydroelectric Power

As discussed in Chapter 5, hydroelectric power measures considered in this study include mean number of spill days per year and mean annual spill volume at the major mainstem Klamath River power facilities (J.C. Boyle, COPCO 1, and Iron Gate), as well as mean annual hydropower generation summed over the four mainstem dams (those listed above plus COPCO 2). For the historical simulation period, mean annual days with spill at the three facilities are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate. The number of spill days and the mean annual spill volumes for J.C. Boyle and COPCO 1 are projected to increase for most scenarios for both future time horizons under the baseline (climate change with no strategies in place). At Iron Gate the projected spill volume generally increases, although by a lower percentage than at J.C. Boyle

and COPCO 1, and the projected mean number of spill days per year shows a small decrease.

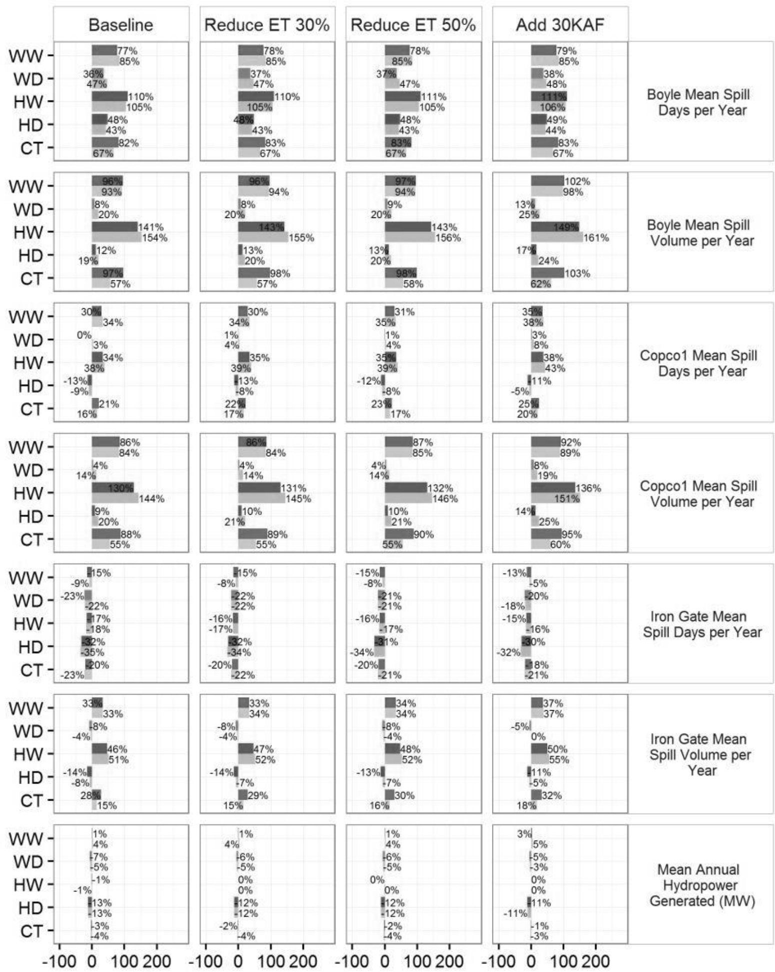
Projected changes in hydropower measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-12 and for the 2070s in Figure 6-13. The adaptation strategy concepts considered generally provide additional water to the mainstem Klamath River, thereby contributing to greater projected increases in mean number of spill days per year, mean annual spill volume, and mean annual hydropower production, more so for the 2070s than for the 2030s future time periods. Again, the addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes than does the decrease in agricultural demands. Projected changes in hydropower production are generally quite small compared with historical simulations, primarily because production under the historical simulation is on the order of 27,000 MW. In other words, hydropower production as a percentage does not change substantially due to the magnitude of hydropower production. Table 6-3 summarizes projected changes in mean annual hydropower production under the CT scenario for both future time periods. Implementation of the Add 30KAF strategy concept results in a 714 or 352 MW reduction in mean annual production for the 2030s, compared to 1,146 or 749 MW for the baseline (depending on consideration of CMIP3- or CMIP5-based projections). For the 2070s, the projected reduction is 468 or 1,209 MW, compared to 818 or 1,593 MW for the baseline.

Projected Hydropower Production

The addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes in hydropower production than does the decrease in agricultural demands. Hydropower production as a percentage does not change substantially due to the magnitude of hydropower production (27,000 MW, according to historical simulations).

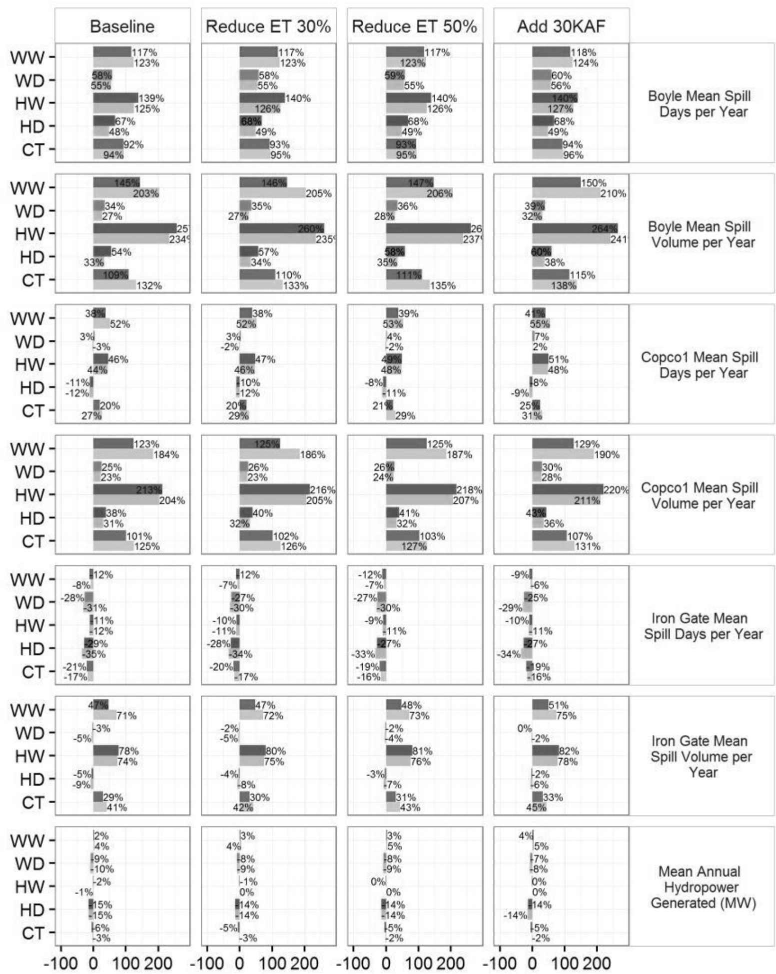
Table 6-3. Summary of projected change in mean annual hydropower production for the Central Tendency scenario in units of MW

Central Tendency Scenario	CMIP	Baseline (MW)	Reduce ET 30% (MW)	Reduce ET 50% (MW)	Add 30KAF (MW)
Historical		26,741			
2030	CMIP3	-1,146	-1,026	-959	-714
	CMIP5	-749	-637	-569	-352
2070	CMIP3	-818	-672	-585	-468
	CMIP5	-1,593	-1,410	-1,290	-1,209



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-12. Projected change in hydroelectric power measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-13. Projected change in hydroelectric power measures for the 2070s with strategies in place, expressed as percent change

6.4.4 Analysis of Impacts – Recreation

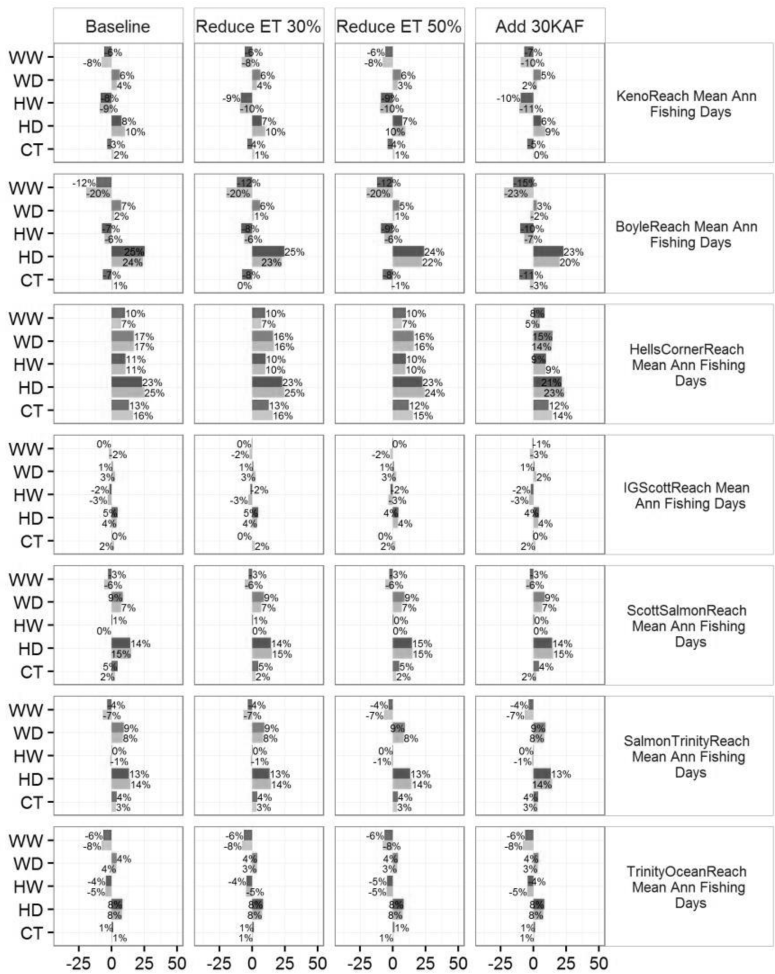
Recreation impacts are measured based on mean annual river boating days and mean annual fishing days in various reaches of the Klamath River. As discussed in Chapter 5, recommended flow ranges were summarized in the Environmental Impact Statement/Report for dam removal (Interior and CDFG, 2012). For the

historical simulations, mean annual number of fishing days are generally greater than mean annual number of river boating days. Projected changes in fishing measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-14 and for the 2070s in Figure 6-15, while projected changes in boating measures are summarized similarly in Figure 6-16 and Figure 6-17. For fishing under the baseline scenario (climate change with no strategies in place), the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios indicate decreases in the number of fishing days for both future time horizons. These results show that recommended flow ranges for fishing do not favor high flows. Because the adaptation strategy concepts generally result in greater mainstem river flows, their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The projected changes are small on a percentage basis (on the order of 1 to 2 percent). Implementation of the strategies does not counter the effects of climate change on fishing days.

Recreation

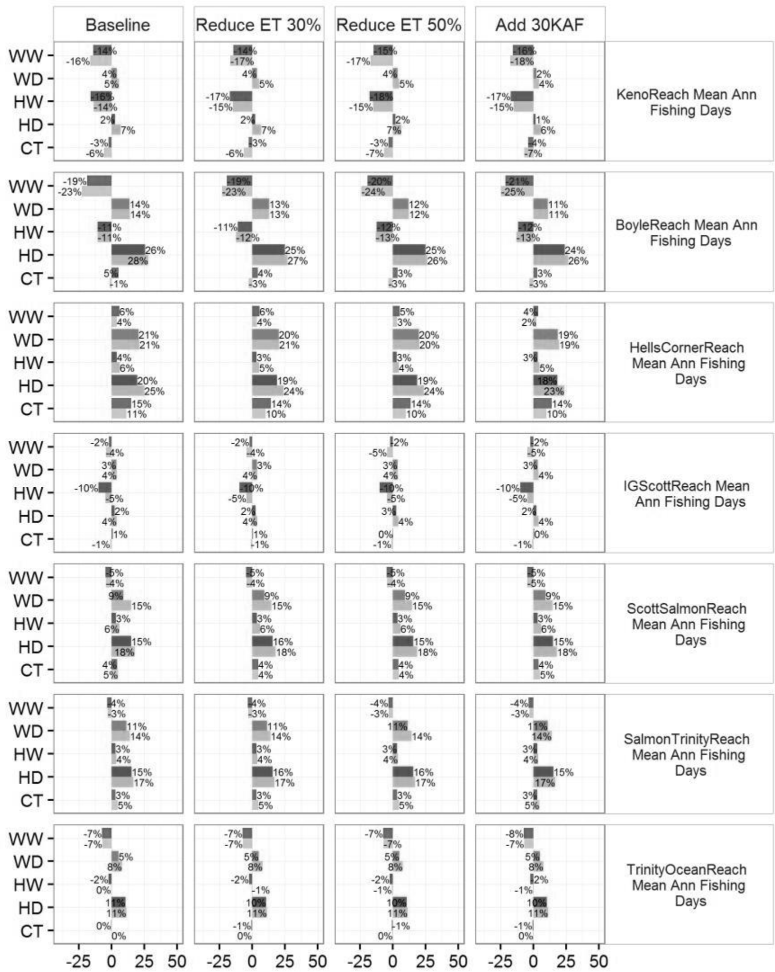
Adaptation strategy concepts generally result in greater mainstem river flows and their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The implementation of adaptation strategy results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario.

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. The implementation of adaptation strategy concepts (both agricultural demand reduction and additional inflow to Upper Klamath Lake) results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario. The strategies do not have a noticeable impact on boating recreation measures downstream of Iron Gate Dam. Upstream of Iron Gate, the strategies cause changes in the boating recreation measures by up to 2 percent for the 2030s and up to 4 percent for the 2070s, and more so for the Add 30KAF strategy scenario than for the agricultural demand reduction scenarios.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

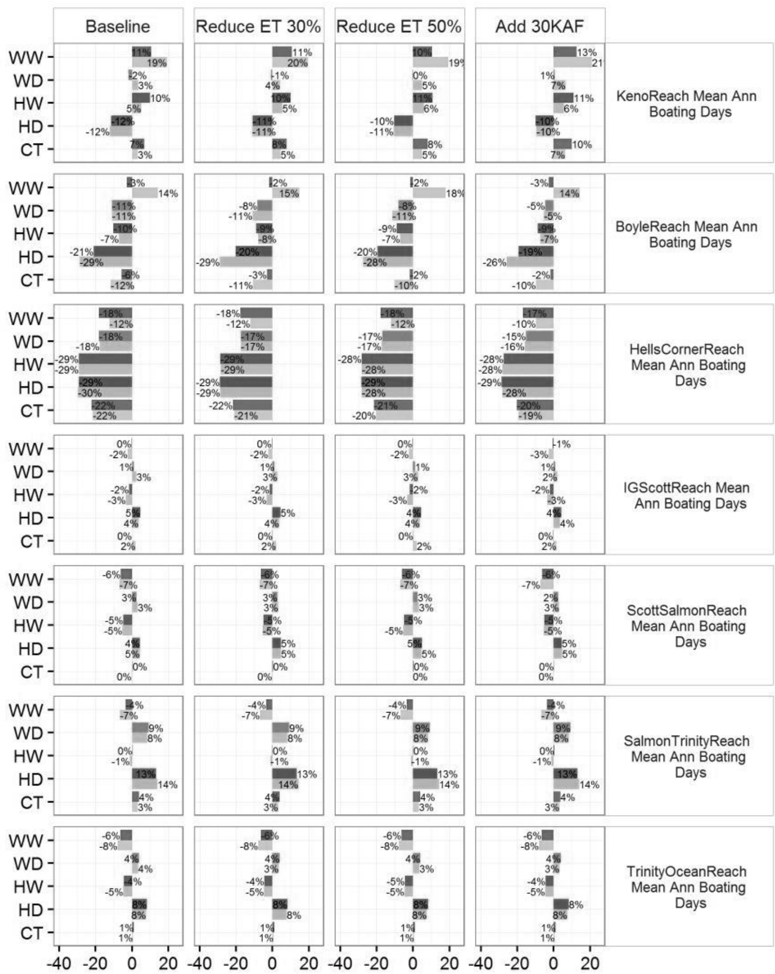
Figure 6-14. Projected change in fishing recreation measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-15. Projected change in fishing recreation measures for the 2070s with strategies in place, expressed as percent change

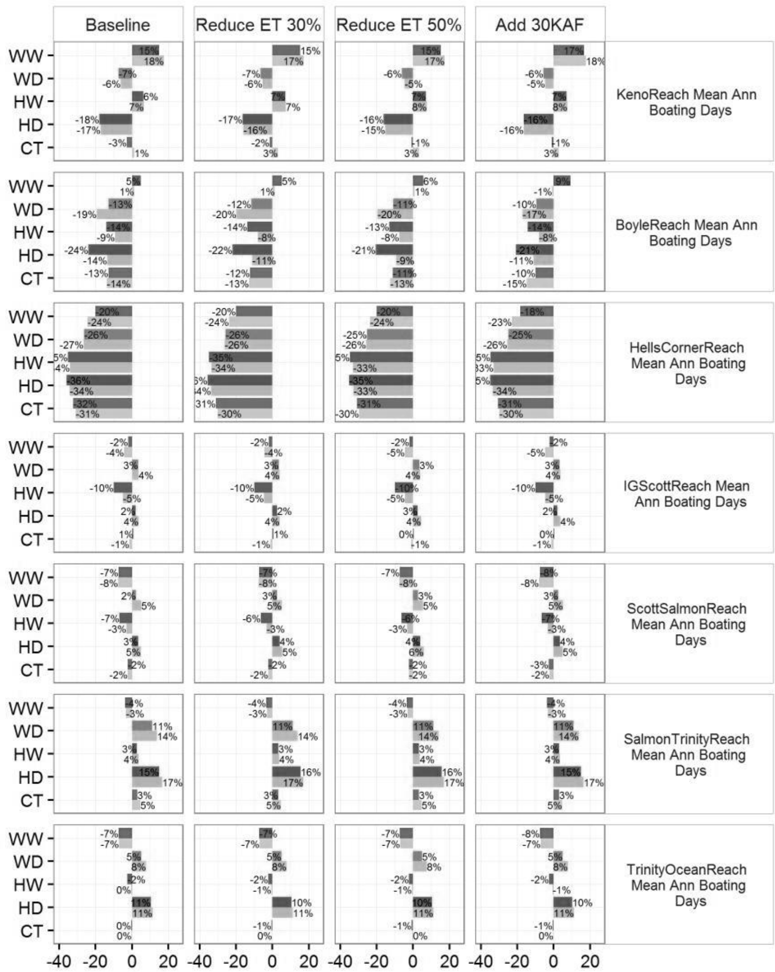
17-01174_013609;17-01174_013609;17-01174_013610;17-01174_013611;17-01174_013612;17-01174_013613;1...



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-16. Projected change in river boating recreation measures for the 2030s with strategies in place, expressed as percent change

17-01174_013609;17-01174_013609;17-01174_013610;17-01174_013611;17-01174_013612;17-01174_013613;1...



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-17. Projected change in river boating recreation measures for the 2070s with strategies in place, expressed as percent change

6.4.5 Analysis of Impacts – Ecological Resources

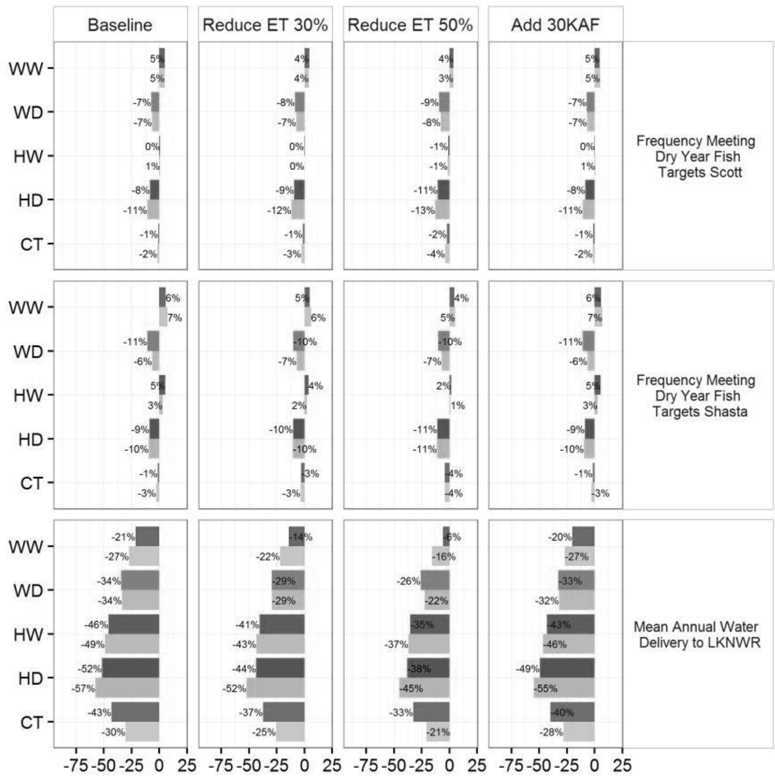
As discussed in Chapter 5, ecological resources measures considered in this study are related to needs for fish and wildlife habitat, including flow targets for SONCC ESU salmon and water supply to Lower Klamath National Wildlife Refuge (LKNWR). According to model simulations under historical hydrology, recommended flow targets that were developed specifically for the Shasta River

Basin were met 57 percent of days for the Shasta River and 71 percent of days for the Scott River (which has higher mean annual flow than the Shasta River).

Projected change in water supply measures under Baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-18 and for the 2070s in Figure 6-19. Projected changes under the baseline in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers indicate increases on a percentage basis for the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and WD), with greater change projected for the 2070s time horizon compared with the 2030s. The baseline CT scenario indicates modest decreases in the frequency of meeting recommended flow targets. The Add 30KAF strategy does not impact flows in the Scott and Shasta Rivers, so the percent change under this strategy is identical to that of the baseline scenario. A reduction in agricultural demand in these basins appears to improve the ability to meet dry year fish targets for some scenarios, but not all.

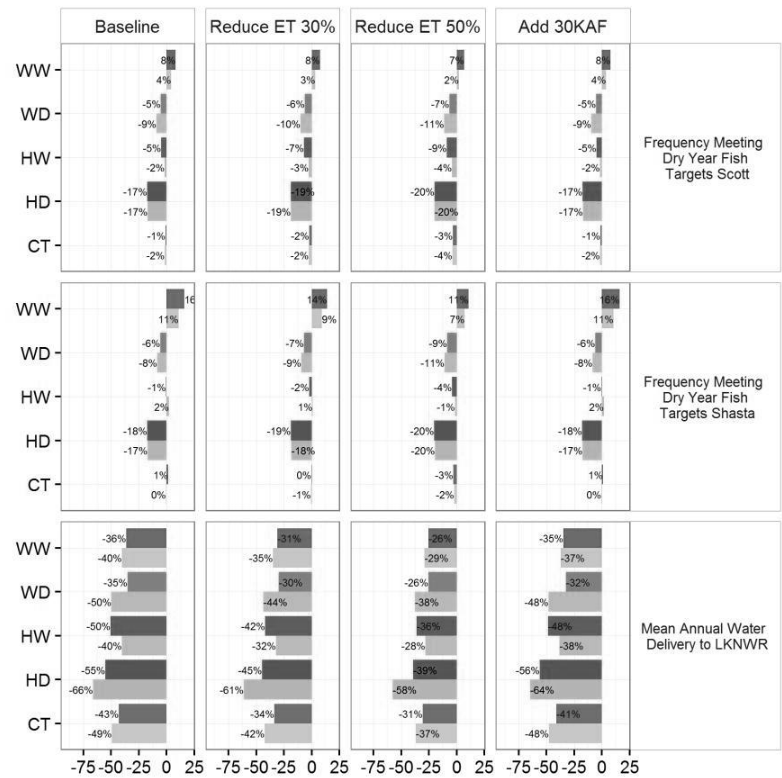
Ecological Resources Impacts

The addition of 30 KAF of inflow to Upper Klamath Lake does not impact flows in the Scott and Shasta Rivers. Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. The additional Upper Klamath Lake inflow scenario also results in greater supply to the refuge, although to a lesser degree.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-18. Projected change in ecological resources measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-19. Projected change in ecological resources measures for the 2070s with strategies in place, expressed as percent change

Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. For the 2030s, the projected reduction in water supply to LKNWR under the CT climate change scenario goes from a reduction of 30 or 43 percent (depending on the use of CMIP3 or CMIP5 scenarios) to a reduction of 21 or 33 percent if agricultural demands are cut in half. The Add 30KAF scenario also results in greater supply to the refuge, although to a lesser degree. For the 2070s, a 50 percent reduction in agricultural demands results in a change in the measure from 43 or 49 percent (under the baseline scenario) to 41 or 48 percent.

It may be noted that model results indicate a decrease in deliveries to LKNWR under all adaptation strategy concepts, albeit to a lesser extent than the baseline

scenario (climate change only). These results may in part be due to the fact that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Since Klamath Project supply is not projected to change substantially as a result of adaptation strategies, projected additional releases from Upper Klamath Lake may provide a greater benefit to the refuge.

6.4.6 Analysis of Impacts – Water Quality

As discussed in Chapter 5, water quality measures considered in this study are related to Klamath River temperature. The SONCC ESU salmon recovery plan (NMFS, 2012) provides a classification of river conditions based in part on the maximum weekly average temperature (MWAT). River temperatures were simulated using the RBM10 water temperature model developed by Perry et al. (2010). According to model simulations under historical hydrology, the river temperatures (as defined by the MWAT) for all simulated years were classified as "poor" under the salmon recovery plan. The "poor" classification threshold is 63.68 degrees F, or 17.6 degrees C. The measure considered by the basin study is the mean annual MWAT.

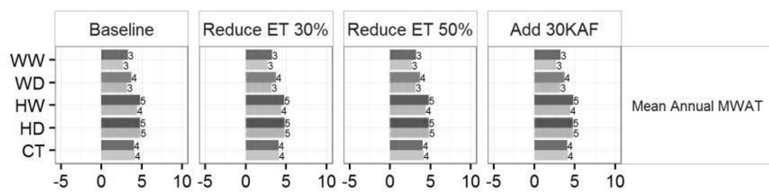
> **Water Quality Impacts**
>
> Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on water quality measures. Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow.

Projected changes in water quality measures under baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-20 and Figure 6-21 and for the 2070s in Figure 6-22 and Figure 6-23. It should be noted that additional adaptation strategy concepts were considered that affect river temperature. One additional strategy (labeled "Reduce Scott Shasta 4degC") focuses on reducing river temperature in the Scott and Shasta rivers by 4 degrees C (about 7 degrees F), in accordance with an existing emergency water management plan in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs.

Other additional strategies fall under the adaptation strategy concept of evaluating the sensitivity of river temperature to changes in tributary river temperature or streamflow. These strategies include adding 10 or 20 percent of flow to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River. These strategies are labeled as "Add Flow 10%" and "Add Flow 20%", respectively. They also include reducing input river temperatures in different locations represented in the RBM10 model. These strategies are labeled "Reduce Tribs 4degC" and "Reduce Dam outflow 4degC." "Reduce Tribs 4degC" includes reduction in temperature for all

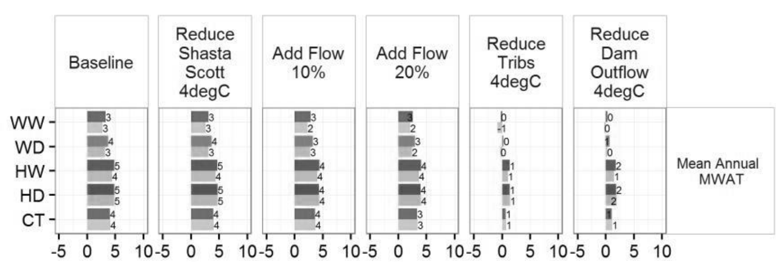
tributaries represented in the RBM10 model. “Reduce Dam Outflow 4degC” includes reducing outflow temperatures by 4 degrees C from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River.

Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on either water quality measure. The 2030s time period (summarized by Figure 6-20) shows no change, while the 2070s time period (summarized by Figure 6-22) shows no change based on reduction of agricultural demand by 30 percent and minimal change for the other two strategies. Figures 6-21 and 6-23 illustrate that Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow. Increasing tributary flows by 20 percent has a minimal impact on Klamath River temperatures, while reducing river temperature at specific locations (where possible) results in countering climate change effects substantially, although less so by the 2070s.



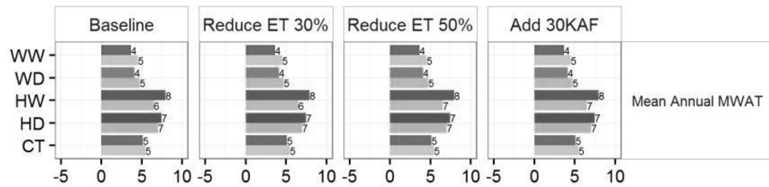
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-20. Projected change in water quality measures for the 2030s with strategies in place, expressed as degrees C



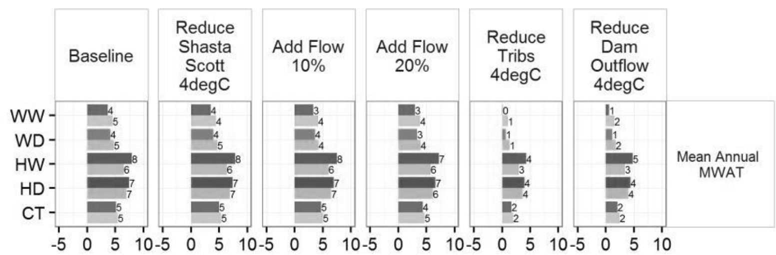
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-21. Projected change in water quality measures for the 2030s with additional strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-22. Projected change in water quality measures for the 2070s with strategies in place, expressed as degrees C



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-23. Projected change in water quality measures for the 2070s with additional strategies in place, expressed as percent change

6.4.7 Analysis of Impacts – Flood Control

As discussed in Chapter 5, flood control measures include (1) the frequency (mean number of days per year) of flood control releases from Upper Klamath Lake, (2) the mean annual flood control release volume (based on water year) from Upper Klamath Lake, and (3) the date of seasonal peak flow at three locations (J.C. Boyle Reservoir, COPCO 1 Reservoir, and Iron Gate Reservoir). Measures are computed using results from the Klamath Basin RiverWare model. Again, flood control release from Upper Klamath Lake is defined in the 2012 Proposed Action for Klamath Project Operations (Reclamation, 2012d), which is quantified as the release beyond that made to meet Klamath Project deliveries and to meet instream flow needs. Projected change in Upper Klamath Lake flood control measures under baseline and adaptation strategy concept scenarios are summarized in Figure 6-24 (2030s) and Figure 6-25 (2070s). Table 6-4 quantifies the difference between projected flood control release volume in units of KAF and the historical baseline, which addresses the question of how much additional surface water may be available for future storage under the “Additional Surface Water Storage Capacity” strategy concept.

The frequency of Upper Klamath Lake flood control release under the historical simulation is about 44 percent of days, while the corresponding mean annual flood control release volume is approximately 224 KAF. As previously discussed, flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. Even under historical hydrology, 44 percent of days may seem high for the percent of days of flood control release from Upper Klamath Lake. The characterization of flood control release is consistent between the RiverWare model and the KBPM. However, greater simulated flows in the Lost River system, compared with KBPM, may result in smaller demand from Upper Klamath Lake for Klamath Project supply, and therefore greater flood control release.

Projected changes indicate minimal change for the wetter scenarios (WW and HW) and a decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. At the same time, for all scenarios there is a projected increase in the mean annual flood control volume, suggesting that more water is being released in the future even though the occurrence of release may be decreasing.

Flood Control Impacts

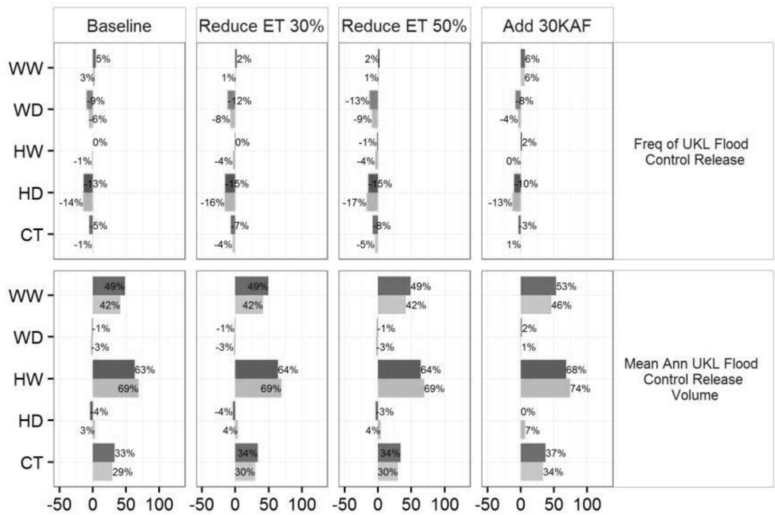
The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume. Model results indicate substantial surface water available for storage in a future climate, due to a combination of decreased snowpack and increased precipitation on an annual basis. Adaptation strategy concepts have small effects on the mean date of seasonal peak flow, indicating a difference of 2 days or less.

Under adaptation strategy concepts in which there is a reduction in agricultural demands, additional water causes greater increases in flood control release for the wetter scenarios, and smaller decreases for the drier scenarios. The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume.

Projected changes in the date of seasonal peak flow are less substantial at J.C. Boyle Reservoir than at COPCO 1 and Iron Gate dams (refer to Table 6-5 through Table 6-7). The baseline scenario dates of seasonal peak flow are April 9 at J.C. Boyle, April 17 at COPCO 1, and April 15 at Iron Gate. Projected baseline scenario climate change effects at J.C. Boyle range from 1 to 4 days later for the 2030s to 4 days earlier to 3 days later for the 2070s, depending on the climate scenario. For COPCO 1 and Iron Gate, projected changes range from 1 day later to 9 days earlier for the 2030s and about 2 days to 2 weeks earlier for the 2070s.

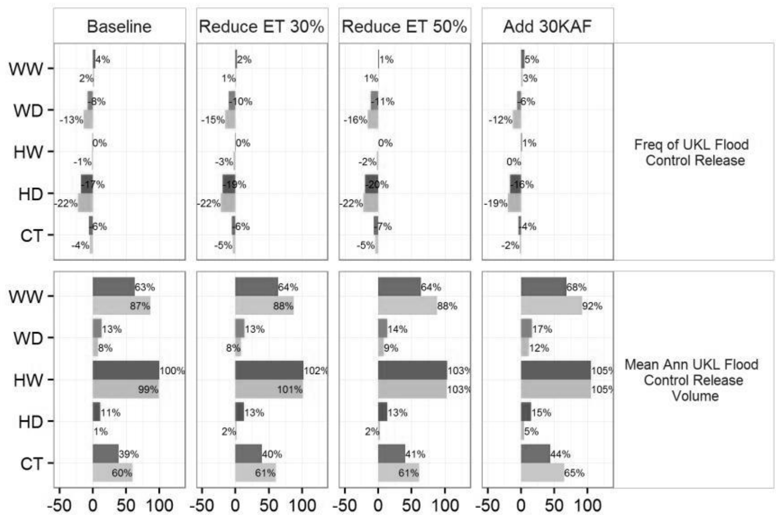
17-01174_013609;17-01174_013609;17-01174_013610;17-01174_013611;17-01174_013612;17-01174_013613;1...

Considering the adaptation strategy concepts and their effect on mean date of seasonal peak flow, both reduction of agricultural demand and addition of 30 KAF of inflow to Upper Klamath Lake have small effects, generally resulting in peak flow dates that are different by 2 days or less from the baseline. This is true at all three dam locations evaluated.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-24. Projected change in flood control measures for the 2030s with strategies in place, expressed as percent change



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-25. Projected change in flood control measures for the 2070s with strategies in place, expressed as percent change

Because the mean annual Upper Klamath Lake flood control release volume is a system performance measure and is also the variable used to quantify the adaptation strategy concept pertaining to additional storage volume, we summarize the projected flood control release volume for all climate change scenarios at both future time horizons. According to model simulations and the means of quantifying flood control release (i.e., that release volume beyond Klamath Project deliveries and environmental flow releases), there may be substantial additional surface water available for storage under future climate conditions. This volume may be due to projected increases in precipitation and/or the reduction in snowpack storage as temperatures are projected to warm.

Table 6-4. Projected change in mean annual Upper Klamath Lake flood control release volume, computed as difference (in units of KAF) between scenario and historical baseline

Scenario	Period	BCSD Projection	Baseline (KAF)	Reduce ET 30% (KAF)	Reduce ET 50% (KAF)	Add 30KAF (KAF)
Historical	Historical	-	224			
Warm Dry	2030	CMIP-3	-6	-5	-5	2
Warm Dry	2030	CMIP-5	-3	-2	-2	5
Warm Wet	2030	CMIP-3	94	94	94	103
Warm Wet	2030	CMIP-5	110	111	111	120
Hot Dry	2030	CMIP-3	8	9	9	16
Hot Dry	2030	CMIP-5	-9	-8	-7	1
Hot Wet	2030	CMIP-3	155	156	156	167
Hot Wet	2030	CMIP-5	142	144	145	153
Central Tendency	2030	CMIP-3	67	67	68	76
Central Tendency	2030	CMIP-5	75	76	77	84
Warm Dry	2070	CMIP-3	19	19	20	27
Warm Dry	2070	CMIP-5	30	31	31	38
Warm Wet	2070	CMIP-3	195	197	198	207
Warm Wet	2070	CMIP-5	143	144	144	153
Hot Dry	2070	CMIP-3	2	5	6	12
Hot Dry	2070	CMIP-5	25	29	31	35
Hot Wet	2070	CMIP-3	224	228	231	236
Hot Wet	2070	CMIP-5	224	230	232	236
Central Tendency	2070	CMIP-3	135	137	138	147
Central Tendency	2070	CMIP-5	87	89	92	99

Table 6-5. Projected change in date of seasonal peak flow at J.C. Boyle Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle
Historical	Historical	-	April 9	-	-	-
Warm Dry	2030	CMIP-3	4	4	4	4
Warm Dry	2030	CMIP-5	4	4	4	3
Warm Wet	2030	CMIP-3	2	2	2	2
Warm Wet	2030	CMIP-5	2	2	2	2
Hot Dry	2030	CMIP-3	4	4	4	3
Hot Dry	2030	CMIP-5	4	4	4	3
Hot Wet	2030	CMIP-3	1	1	1	1
Hot Wet	2030	CMIP-5	2	2	2	2
Central Tendency	2030	CMIP-3	3	3	3	3
Central Tendency	2030	CMIP-5	2	2	2	1
Warm Dry	2070	CMIP-3	2	4	3	2
Warm Dry	2070	CMIP-5	3	3	3	3
Warm Wet	2070	CMIP-3	2	2	2	1
Warm Wet	2070	CMIP-5	2	2	2	2
Hot Dry	2070	CMIP-3	3	4	3	2
Hot Dry	2070	CMIP-5	1	2	2	1
Hot Wet	2070	CMIP-3	-2	1	-2	-3
Hot Wet	2070	CMIP-5	-4	-3	-3	-4
Central Tendency	2070	CMIP-3	0	3	0	0
Central Tendency	2070	CMIP-5	2	2	2	2

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

Table 6-6. Projected change in date of seasonal peak flow at COPCO 1 Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1
Historical	Historical	-	April 17	-	-	-
Warm Dry	2030	CMIP-3	1	1	1	1
Warm Dry	2030	CMIP-5	0	0	0	0
Warm Wet	2030	CMIP-3	-4	-4	-4	-5
Warm Wet	2030	CMIP-5	-5	-5	-5	-5
Hot Dry	2030	CMIP-3	-4	-3	-3	-4
Hot Dry	2030	CMIP-5	-3	-3	-3	-3
Hot Wet	2030	CMIP-3	-9	-9	-9	-9
Hot Wet	2030	CMIP-5	-8	-8	-8	-8
Central Tendency	2030	CMIP-3	-3	-4	-3	-4
Central Tendency	2030	CMIP-5	-6	-6	-6	-6
Warm Dry	2070	CMIP-3	-5	-5	-4	-5
Warm Dry	2070	CMIP-5	-2	-2	-2	-2
Warm Wet	2070	CMIP-3	-7	-7	-7	-7
Warm Wet	2070	CMIP-5	-7	-7	-7	-7
Hot Dry	2070	CMIP-3	-8	-7	-7	-8
Hot Dry	2070	CMIP-5	-8	-8	-8	-8
Hot Wet	2070	CMIP-3	-15	-15	-14	-15
Hot Wet	2070	CMIP-5	-17	-17	-17	-17
Central Tendency	2070	CMIP-3	-10	-10	-10	-11
Central Tendency	2070	CMIP-5	-7	-7	-7	-7

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

Table 6-7. Projected change in date of seasonal peak flow at Iron Gate Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate
Historical	Historical	-	April 15	-	-	-
Warm Dry	2030	CMIP-3	1	1	1	0
Warm Dry	2030	CMIP-5	0	0	0	0
Warm Wet	2030	CMIP-3	-4	-4	-4	-4
Warm Wet	2030	CMIP-5	-5	-5	-5	-5
Hot Dry	2030	CMIP-3	-4	-4	-4	-4
Hot Dry	2030	CMIP-5	-3	-3	-3	-3
Hot Wet	2030	CMIP-3	-9	-9	-9	-9
Hot Wet	2030	CMIP-5	-8	-8	-8	-8
Central Tendency	2030	CMIP-3	-4	-4	-4	-4
Central Tendency	2030	CMIP-5	-6	-5	-5	-6
Warm Dry	2070	CMIP-3	-5	-5	-5	-5
Warm Dry	2070	CMIP-5	-2	-2	-2	-2
Warm Wet	2070	CMIP-3	-7	-7	-7	-7
Warm Wet	2070	CMIP-5	-7	-7	-7	-7
Hot Dry	2070	CMIP-3	-7	-7	-7	-7
Hot Dry	2070	CMIP-5	-8	-8	-7	-8
Hot Wet	2070	CMIP-3	-14	-14	-13	-14
Hot Wet	2070	CMIP-5	-16	-16	-15	-16
Central Tendency	2070	CMIP-3	-10	-10	-10	-10
Central Tendency	2070	CMIP-5	-7	-7	-7	-7

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

6.5 Key Findings and Next Steps

Klamath River water users and stakeholders have long have long called for a comprehensive and integrated approach to water management to balance the needs of all water users. The Basin Study Report evaluates current and projected future water supply and demand assessments to refine existing projections of climate change's effect on the Klamath River Basin, and provide stakeholders in the region the opportunity to identify and evaluate potential adaptation strategies which may reduce identified imbalances. These adaptation strategies provide water users, stakeholders, and Reclamation with understanding of the degree to which actions including those to increase supply, decrease demand, and modify operations could reduce supply and demand imbalances that are projected to increase as a result of climate change. The Basin Study builds on earlier work and is the next significant step in developing a comprehensive knowledge base

and suite of tools and options that could address the risks posed by Klamath River Basin water supply-demand imbalances.

Results from model simulations with and without adaptation strategy concepts in place indicate that the strategies have modest abilities to reduce climate change impacts. Considered strategies include agricultural water conservation, additional inflow to Upper Klamath Lake, quantification of potential surface water storage, and evaluation of changes in flow and tributary temperature on Klamath River temperature at Klamath, California.

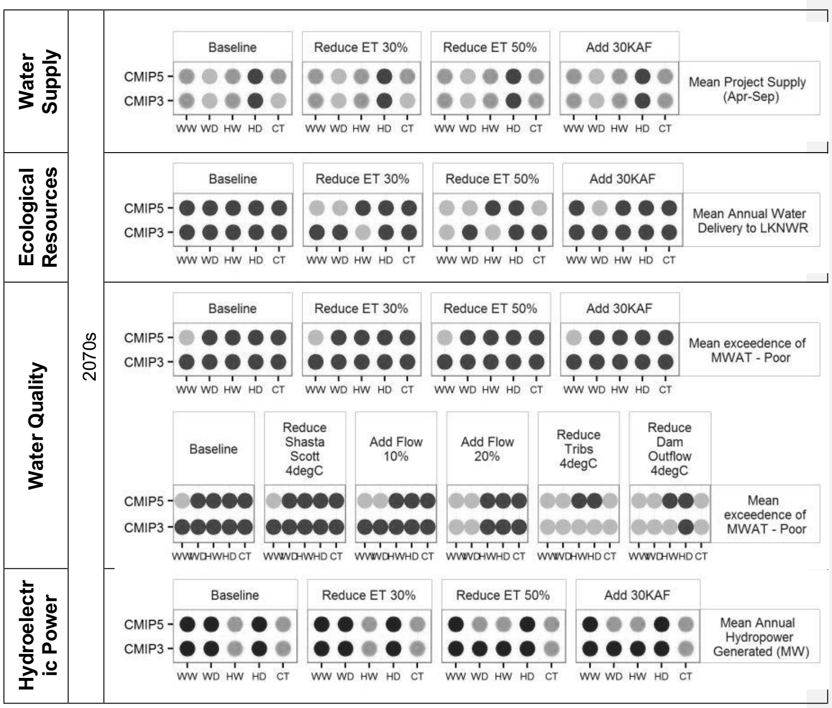
The addition of inflow to Upper Klamath Lake appears to result in the greatest change in computed basin-wide response variables and selected performance measures. With respect to sensitivities of river temperature, the reduction in tributary temperature has a greater impact than does change in flow. Also, according to model simulations, substantial surface water may be available for storage in the future due to reduction in snowpack storage and projected changes in precipitation timing and volume. The location for quantification of additional storage is at Upper Klamath Lake; however, this study does not explore locations for future surface water storage.

Figure 6-26 summarizes projected changes in four select system performance measures for the 2070s future time period, compared with the historical simulation. Projected changes are computed using CMIP3- and CMIP5-based projections, and for each of the five climate change scenarios. The baseline scenario represents climate change only, without adaptation strategy concepts in place. The other scenarios represent changes with adaptation strategy concepts. For this figure, projected changes on a percentage basis were divided into four bins: two bins for positive change and two bins for negative change. Darker circles represent the bin with greater change. Green circles indicate an improvement in the selected measure, while red circles indicate a worsening of the measure. The results summarized in the figure allow for a high level understanding of the direction of change, and highlight which strategies provide the greatest change compared with the baseline scenario.

In Figure 6-26, with respect to mean April–September Klamath Project supply, neither reduction in agricultural demand nor additional Upper Klamath Lake inflow of 30 KAF cause a substantial change compared with the baseline scenario. For mean annual water supply to LKNWR, reduction in agricultural demands results in a meaningful improvement, compared with the baseline scenario. For mean exceedance of the “poor” water quality classification (through calculation of the MWAT), reduction in tributary water temperatures has a greater influence on resulting river temperatures than changes in streamflow. It is likely not realistic to expect a reduction in temperatures in unmanaged tributaries, but changes in managed flows (i.e., Link River, Shasta River, Scott River, Trinity River) still have a meaningful impact, compared with the baseline scenario. For mean annual hydropower generation, it is apparent that climate change, and adaptation strategy concepts, result in greater hydropower production. Reduction

of agricultural demands by 50 percent and additional Upper Klamath Lake inflow of 30 KAF result in noticeable change from the baseline, while a less substantial reduction in agricultural demands (30 percent) does not provide substantial additional benefit.

Overall, climate change adversely affects mean annual deliveries to LKNWR and river temperatures; it may adversely affect or may be favorable to mean Klamath Project Supply (April–September) depending on the climate change scenario, and is likely to be favorable to mean annual hydropower production. Adaptation strategy concepts evaluated in the Basin Study do not substantially counter the effects of climate change. However, in general the addition of 30 KAF inflow to Upper Klamath Lake appears to have a greater benefit to the system reliability than does reduction in agricultural demands, based on model simulations.



Notes: Green circles indicate an improvement in the measure for the future, while red circles indicate a worsening in the measure for the future. Darker circles indicate greater change than lighter circles.

Figure 6-26. Summary of projected changes in select measures for the 2070s, with and without strategies in place

6.5.1 Refinement of Adaptation Strategies and Next Steps

The Basin Study Report indicates that implementation of projects to improve water supply, decrease demand, and modify operations can provide some improvement in the reliability and sustainability of the Klamath River system to help meet current and future water demands. The adaptation strategies evaluated in this Basin Study would all need to be further studied to refine the understanding of these potential benefits and develop plans for their implementation. Similar to this Basin Study, the agencies and stakeholders that would need to be involved in that refinement process would need to include all those potentially affected by their implementation.

The Klamath River Basin Study relied on projected future conditions that were developed utilizing existing model frameworks and inputs. Identified adaptation strategies evaluated by the Basin Study are general (i.e., not specific proposed projects) by design and are intended to identify sensitivities of the Klamath Basin to various types of potential actions. Moving forward, a number of tasks have been identified to further enhance our understanding of climate change impacts on the Klamath River Basin.

- Refinement of ecosystem demands and vulnerabilities – Additional analysis of the relationship between changes in the climate, changes in the demands of aquatic, wetland, and riparian ecosystems that result from changes in the climate, and the ability to accommodate these demands with existing supplies would further support and refine the findings in this study. Additionally, incorporation of developing river temperature modeling for the Trinity River by the U.S. Geological Survey could enhance our understanding of climate change impacts and implemented adaptation strategies on river temperatures.

- Coupled groundwater/surface water model development – Expansion of existing groundwater models for the Scott and Shasta rivers to cover broader portions of the basin would further support the analysis completed in this Basin Study.

- Reservoir Operations Refinement – Current funding by the Bureau of Reclamation Office of Policy for a Klamath River Basin reservoir operations pilot study on Upper Klamath Lake will enhance the ability to quantify Upper Klamath Lake inflows and provide for an improved understanding of Upper Klamath Lake operations.

- Effects of future policy changes – Evolving policy conditions are anticipated in the Klamath River Basin relating to future ESA consultations and potential removal of the four mainstem Klamath River dams. Continued analysis of future policies using the Basin Study modeling framework will allow for comparisons to be made, and for greater understanding of potential climate change impacts.

6.6 References Cited

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RECLAMATION

Managing Water in the West

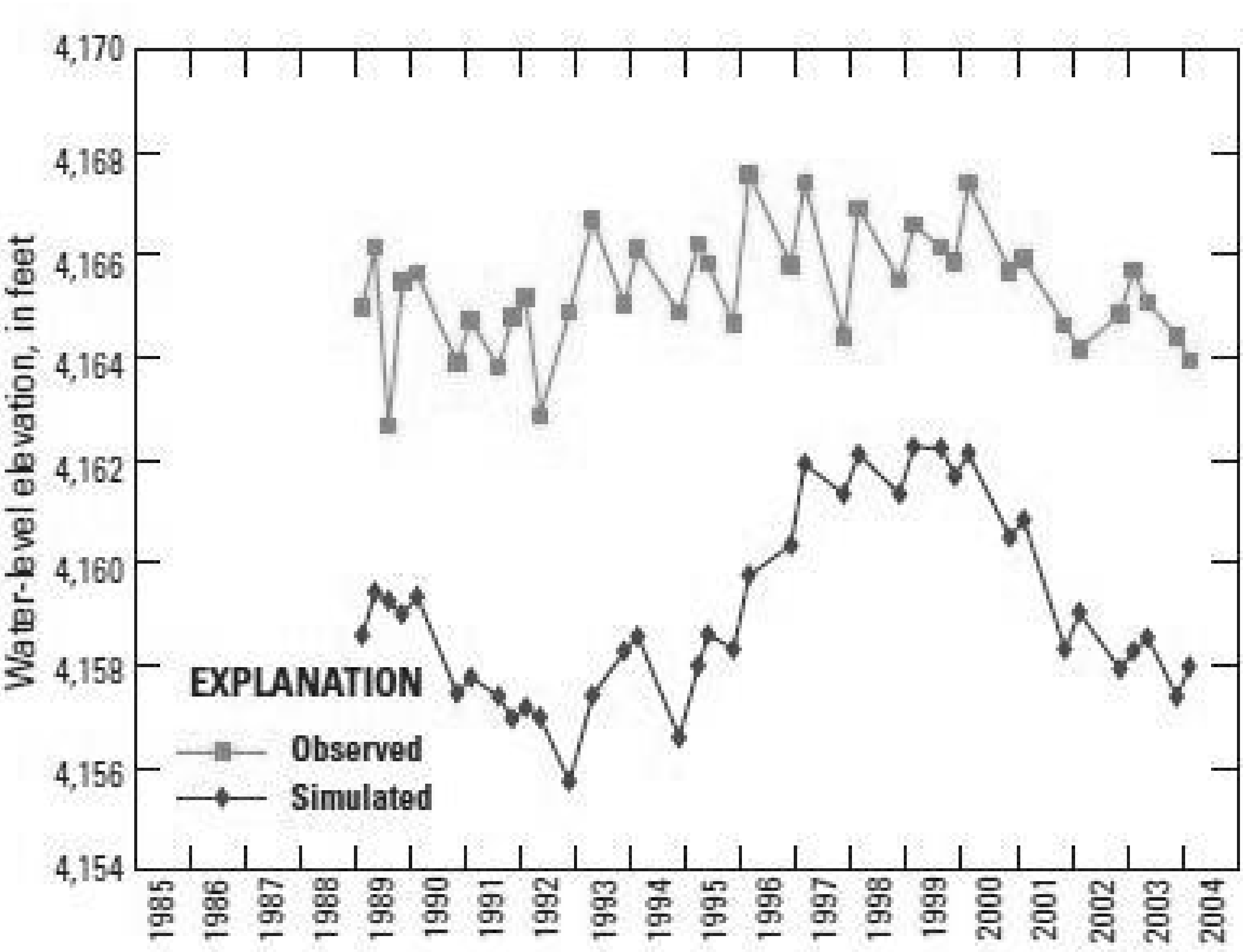

Figure 18. Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

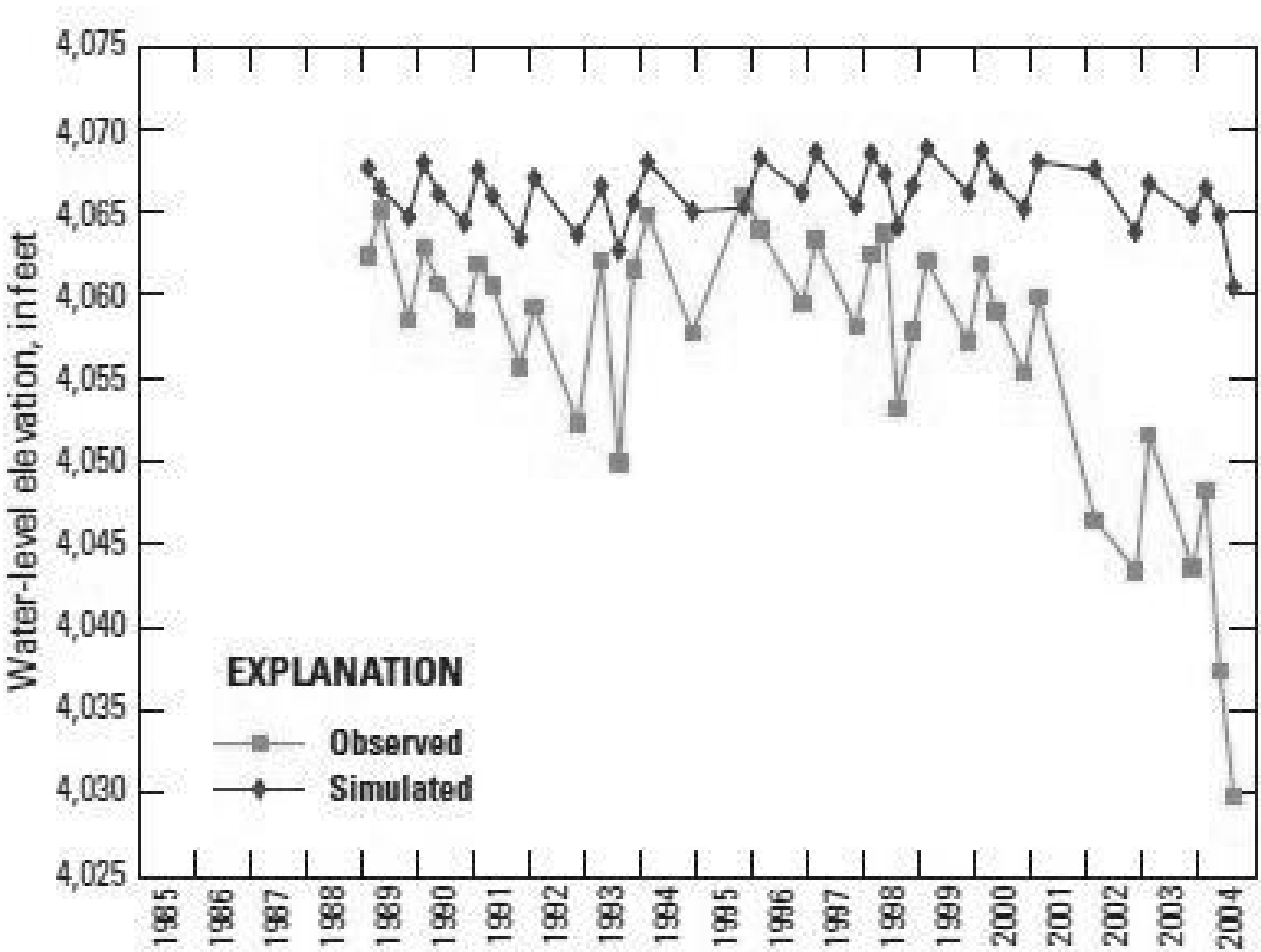

Figure 36. Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

To: Aragon-Long, Susan[sgandara@usgs.gov]
From: Goklany, Indur
Sent: 2017-09-01T15:48:38-04:00
Importance: Normal
Subject: Re: Review due COB 8/30: NCA4 Inter-agency Review
Received: 2017-09-01T15:49:12-04:00
DOI OfflineComments_NCA4_SGCR img2.xlsm
DOI OfflineComments_NCA4_SGCR img1.xlsm
FF and well-being.pptx

Susan,
Attached are my comments on the first two chapters, and a Power Point that contains supporting information referred to in comments on the first chapter. [redacted] (b)(5)

I really appreciate the fact that you gave me extra time. My consolation for not getting to the rest of the document is that I will probably have other bites at these apples --unfortunate analogy: reminds me that I skipped lunch!

Best regards,
Indur Goklany
202-208-4951

On Tue, Aug 29, 2017 at 3:30 PM, Aragon-Long, Susan <sgandara@usgs.gov> wrote:

> Just pick a chapter or two and the Intro/Overview. This is really all we're expecting from each of our DOI reviewers. It was distributed widely, so if everyone just reviews chapters within their area of expertise, we'll be in good shape.
> Susan

On Tue, Aug 29, 2017 at 3:24 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

> Thanks. Just started reading this.

On Tue, Aug 29, 2017 at 3:20 PM, Aragon-Long, Susan <sgandara@usgs.gov> wrote:

> [redacted] (b)(6)

On Tue, Aug 29, 2017 at 3:18 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

> Thanks Susan. Do you have a phone number?

On Tue, Aug 29, 2017 at 3:15 PM, Aragon-Long, Susan <sgandara@usgs.gov> wrote:

> Hello everyone,
> This is just a 2nd order draft. There will be other opportunities to review subsequent

drafts, but I know that those requests will also have the same short (a couple of weeks) timelines. Agency clearance won't happen until next year sometime as we're nowhere near that stage yet. The chapters are short (6-20 pages), [redacted]

Please don't hesitate to call or email if you have additional questions. My drop dead date is Friday, so please get me your comments by then at the very latest.

Susan

On Tue, Aug 29, 2017 at 3:06 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

> Not as yet. Thanks for sending this on. I was trying to locate the incoming via OCL and even OMB, but was unable to locate it.
> I am not sure that I can do a decent review in one day, and would not recommend clearance based on a cursory review. So I have a basic question: Is this the final review and will we have other opportunities to look at this and give it a good scrub?

Perhaps Susan, who has been added to this e-mail, can answer that question.

Thanks.
Goks

On Tue, Aug 29, 2017 at 1:53 PM, Shawn Buckner <shawn_buckner@ios.doi.gov> wrote:

Hi Goks,

Are you involved in this review?

Thank you,
Shawn

Begin forwarded message:

From: "Johnson, Liza" <liza_m_johnson@ios.doi.gov>
Date: August 29, 2017 at 11:43:57 AM EDT
To: Karla Cook <karla.cook@boem.gov>, Angela Gustavson <Angela_Gustavson@fws.gov>, "Ann (USGS) Tihansky" <tihansky@usgs.gov>, "Argo, Emily" <eargo@usgs.gov>, Barbara Pitkin <Barbara_Pitkin@ios.doi.gov>, "Blythe, Brad" <brad.blythe@boem.gov>, Brian Carlstrom <brian_carlstrom@nps.gov>, "Burgos Rodriguez, Jhoset"

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Subject: Review due COB 8/30: NCA4 Inter-agency Review

Dear SOPT and Regional Contacts,

The draft National Climate Assessment 4th edition (NCA4) is out for DOI review, with a due date of **COB tomorrow, 8/30**. The draft chapters are available for download here: https://drive.google.com/drive/folders/0B2rKFOZf-8Y6b3hMOXZtM2xCMW8

Chapter 8 deals with the coasts, and Chapter 9 deals with the ocean and marine resources. There are several other chapters that may be of interest, including those on energy, tribal and indigenous peoples, and various regional chapters.

If you would like to provide comments, please use the attached instructions and offline comment form and return to **Susan Aragon-Long**(sgandara@usgs.gov).

Apologies for the short turn-around. I just received the draft today and have asked for an extension, but we're unlikely to get one.

Best,
Liza

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Fossil Fuels, and Human and Environmental Well-Being

Indur M. Goklany
Independent Scientist

International Climate Change Conference - 12
Washington, DC, March 23-24, 2017

17-01174_013949;17-01174_013949;17-01174_013950;17-01174_013951;17-01174_013952;17-01174_013953;1...

three warmest years on record

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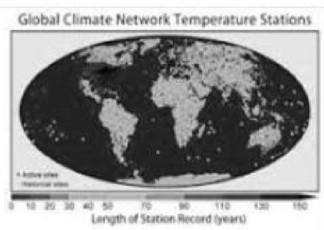
Warmest years

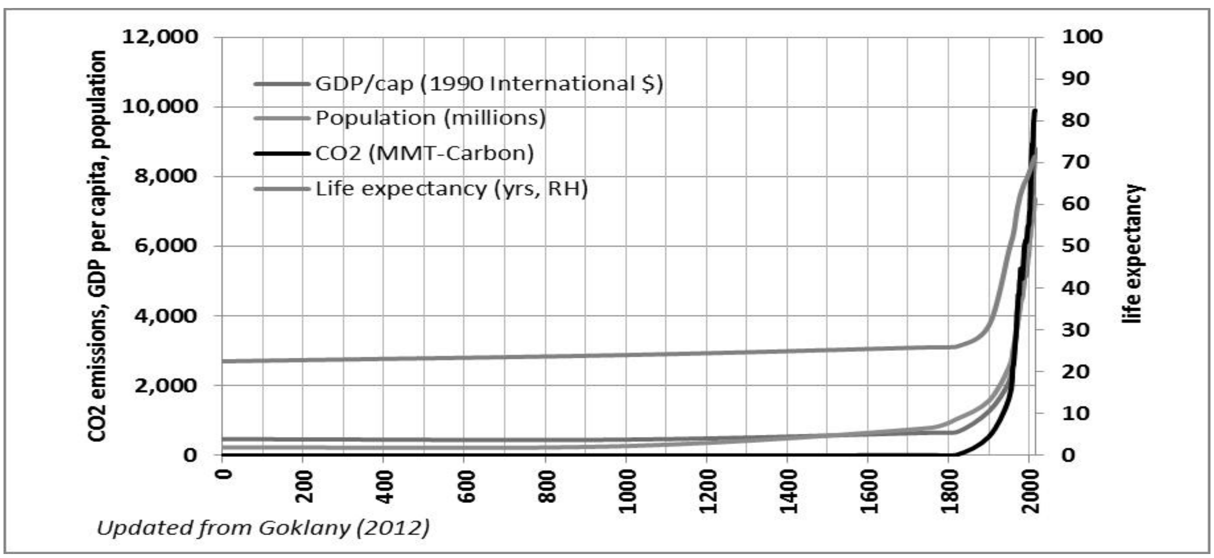
Rank	Year	Anomaly °F
1	2016	1.69
2	2015	1.62
3	2014	1.33
4	2010	1.26

8 more rows



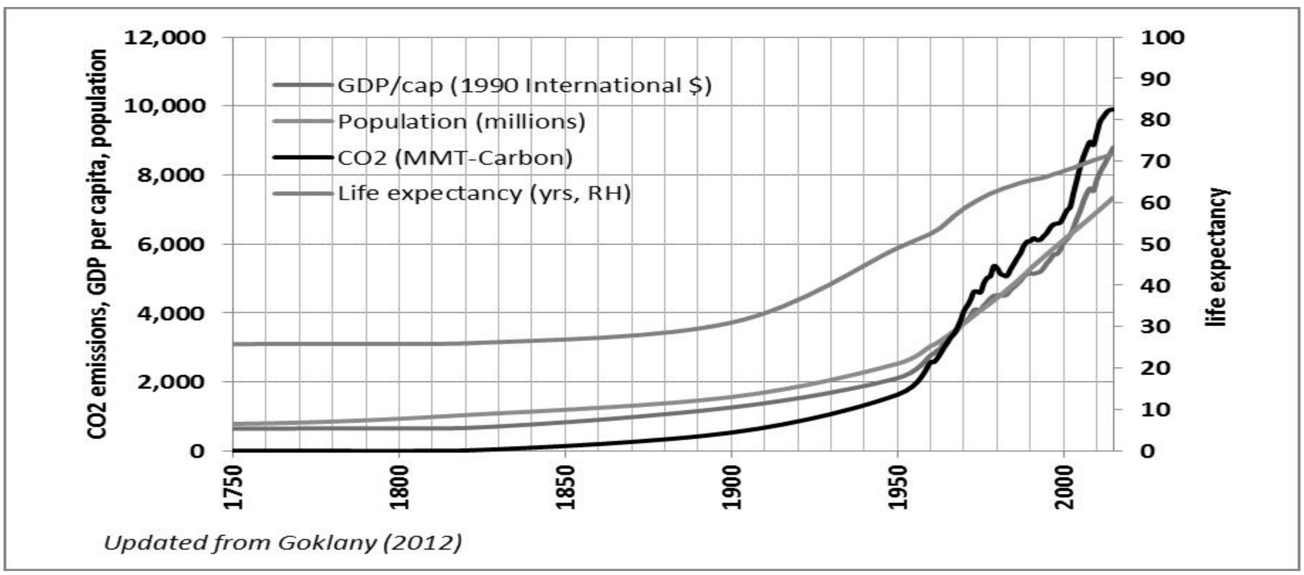
Instrumental temperature record - Wikipedia
https://en.wikipedia.org/wiki/Instrumental_temperature_record

Human Progress & CO2 Emissions, AD 1–2015



Update based on World Bank (2017); Le Quéré et al. (2016), via CDIAC

Human Progress & CO2 Emissions, AD 1750–2015



Update based on World Bank (2017); Le Quéré et al. (2016), via CDIAC

Average growth rates (%): population, prosperity life expectancy, and CO2 emissions, AD 1–2014

	AD 1–1000 (%)	AD 1000–1750 (%)	AD 1750–2014 (%)
Population	**0.02**	**0.14**	**0.85**
Prosperity (GDP per capita)	**0.00**	**0.05**	**0.99**
Life expectancy	**0.01**	**0.01**	**0.39**
CO2 emissions			**3.12**

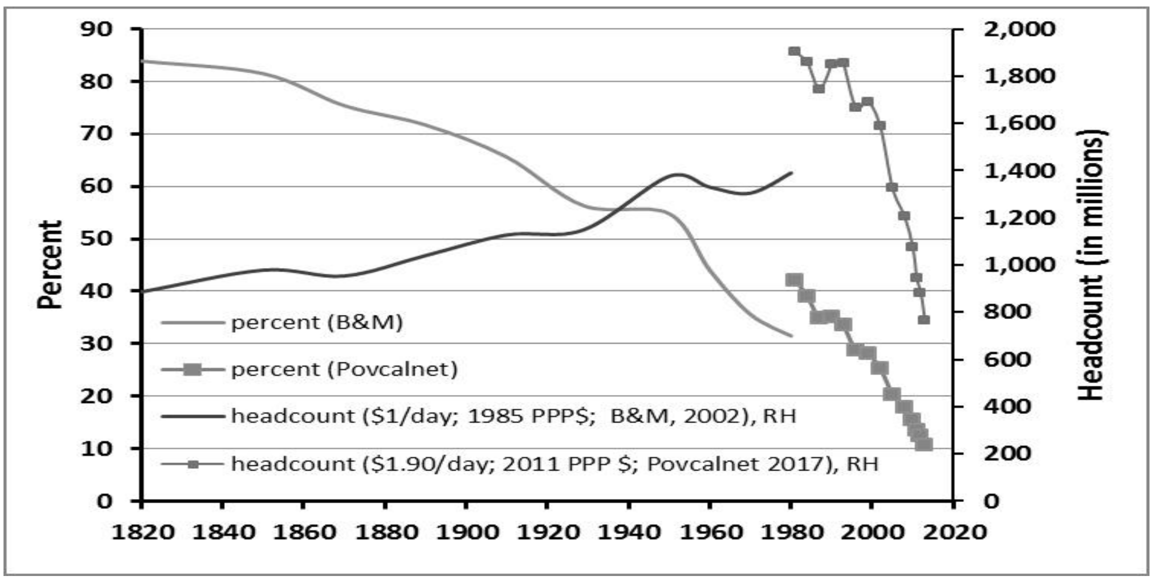
Sources: Angus Maddison, Statistics on World Population, GDP and Per Capita GDP, 1–2008 AD, University of Groningen, 2010, http://www.ggdc.net/MADDISON/Historical_Statistics/vertical-file_02-2010.xls; World Bank, World Development Indicators 2011, http://databank.worldbank.org/; T. A. Boden, G. Marland, and R. J. Andres, Global, Regional, and National Fossil-Fuel CO2 Emissions, http://cdiac.ornl.gov/trends/emis/overview_2008.html.

Living longer and healthier, but CO2 is going up!

	Life expectancy in 1950 (unadjusted) (yrs)	Health-adjusted life expectancy – 2000 (yrs)	Health-adjusted life expectancy – 2015 (yrs)
China	**41**	**64.6**	**68.5**
India	**32**	**54.2**	**59.6**
USA	**68**	**67.2**	**69.1**
World	**49**		**63.1**
Atmospheric CO2 level (ppm)	**311**	**370**	**401**

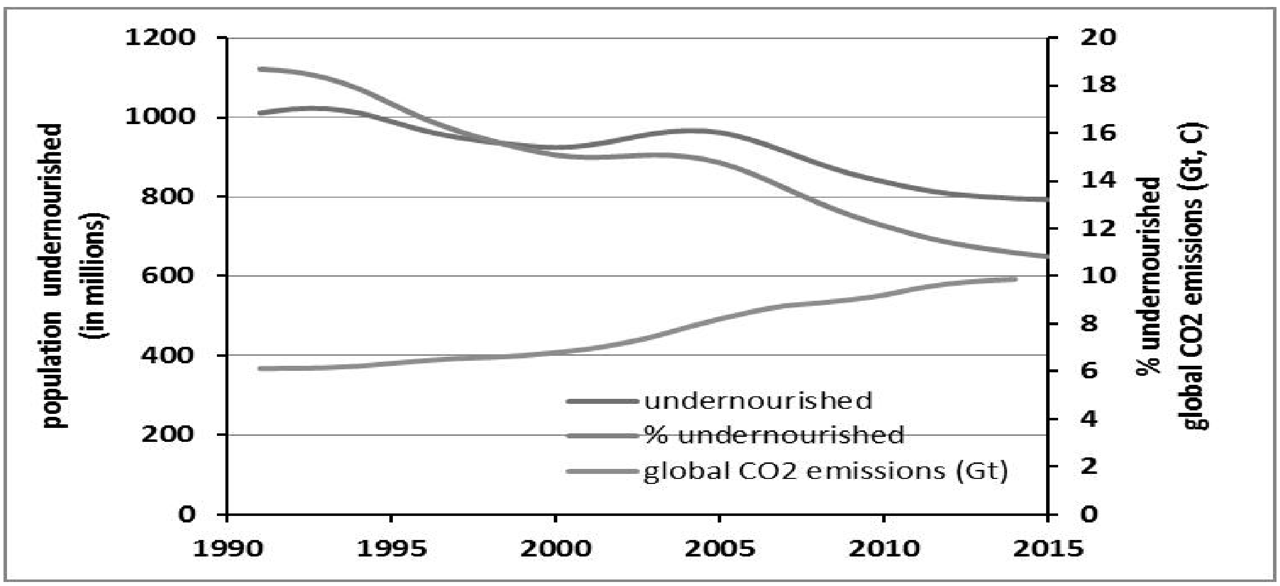
Sources: Maddisson (2001), p.30; ESRL Mauna Loa data, ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_mlo.txt; WHO (2016), http://gamapserver.who.int/gho/interactive_charts/mbd/hale_1/atlas.html .

Global Poverty, 1820–2013



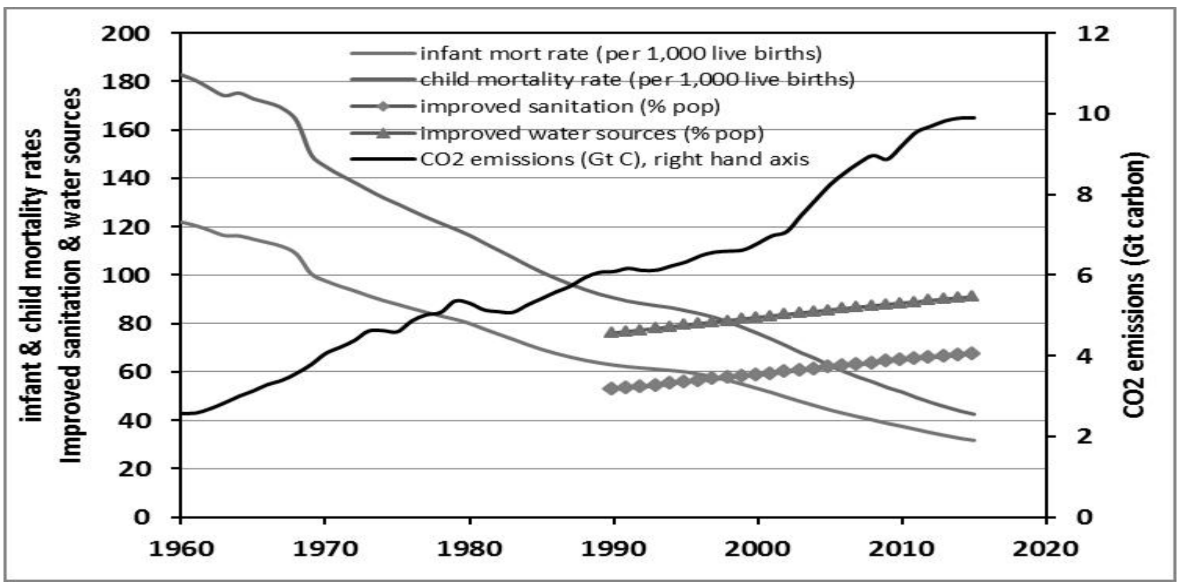
Sources: Morrison & Bourginon (2002), World Bank (2017)

Global Hunger & CO2 Emissions, 1991–2015



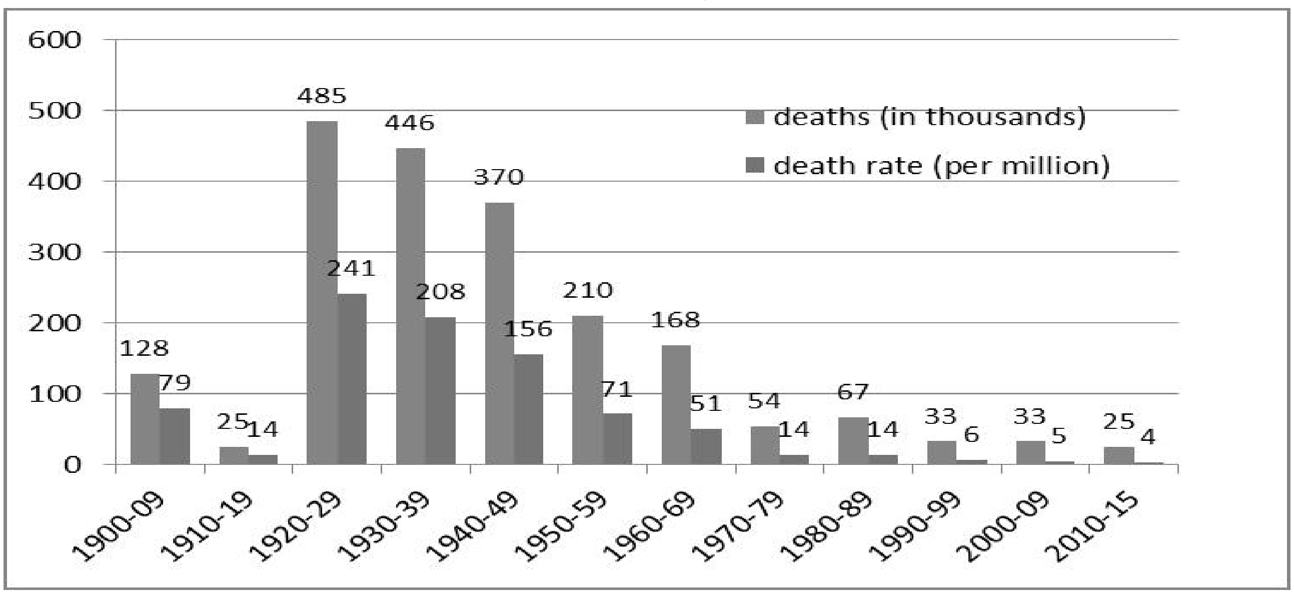
Sources: FAO (2016); Le Quéré et al. (2016), via CDIAC

Trends: CO2 Emissions & Various Measures of Human Well-Being, 1960–2015



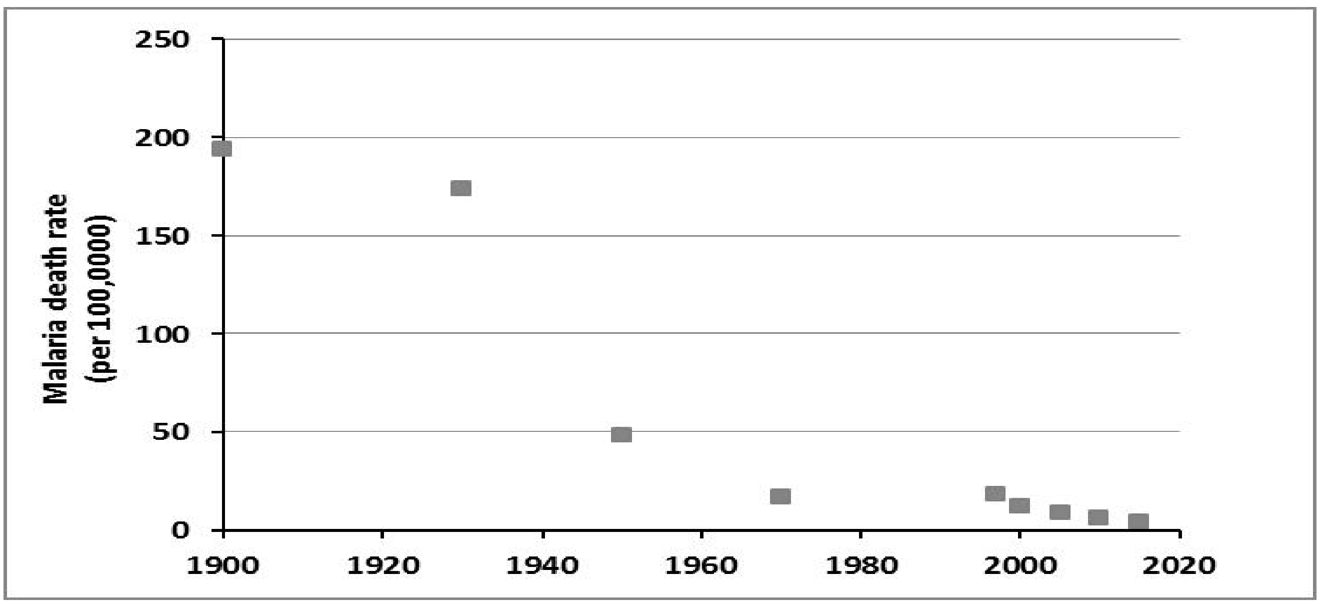
Sources: World Bank (2017); Le Quéré et al. (2016), via CDIAC

Global deaths & deaths rates from extreme weather events, 1900–2015



Sources: Updated from Goklany (2009) using EM-DAT (2017) and World Development Indicators (2017)

Global malaria death rates, 1900–2015



Sources: 1900-1997: World Health Report 1999, Chapter 4; 2000-2015: World Malaria Report 2016

Planet is greener, mainly from FF related factors (70% CO2, 9% N-deposition, 8% climate change)

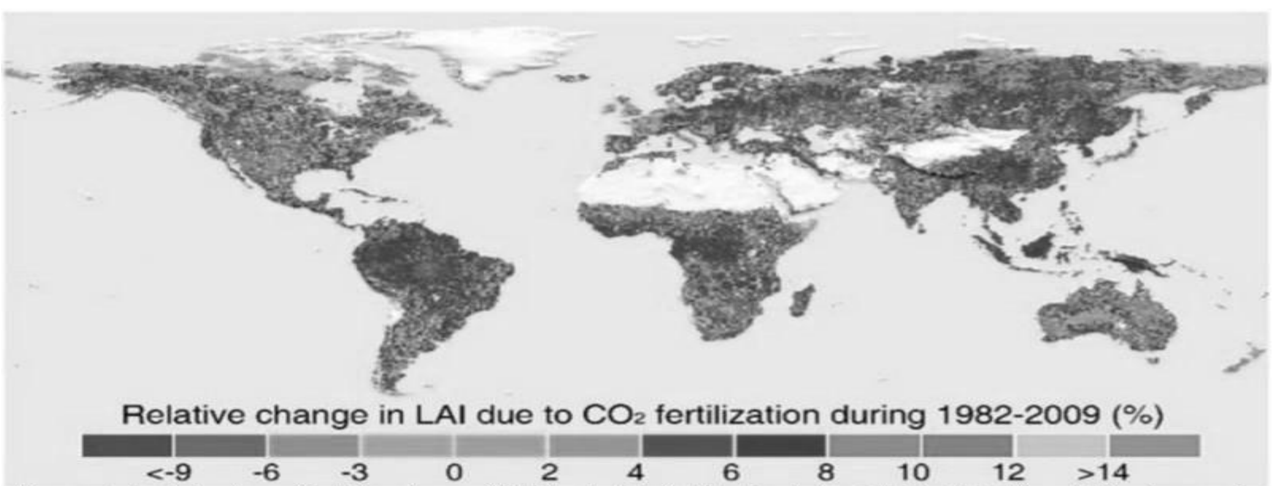
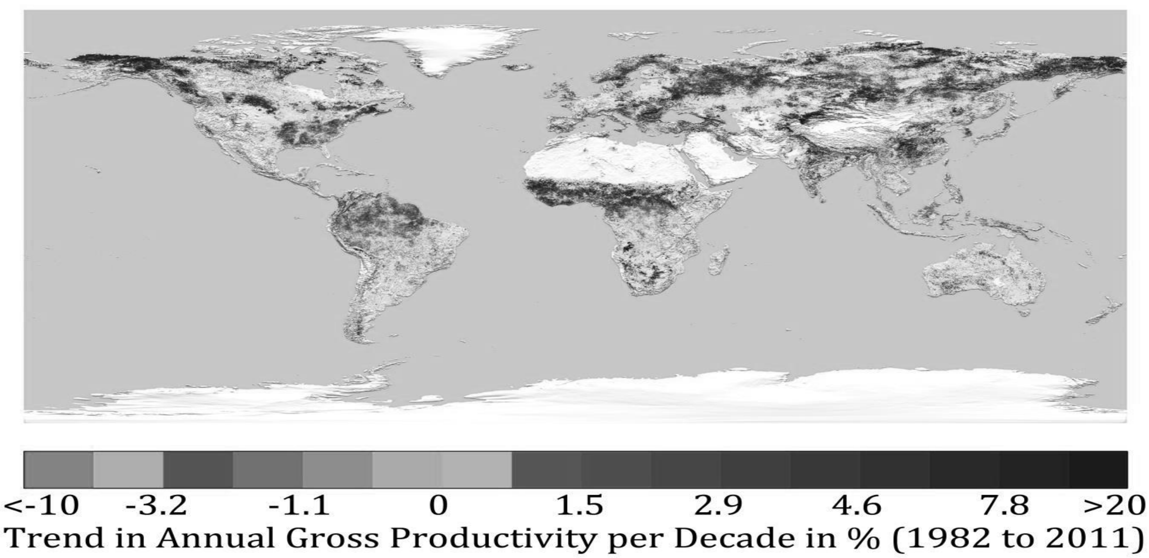


***Figure 1**. Spatial pattern of relative change of LAI due to CO_2 fertilization during 1982 to 2009. The relative change of LAI in each pixel is derived from the ratio of the increment of LAI driven by elevated atmospheric CO_2 to the 28-year average value of LAI simulated by model ensemble mean under scenario S1. Source: Figure S12, supplementary information from Zhu et al. (2016)*

Earth is more productive [14% increase in gross productivity, 1982–2011]



Zhu & Myneni (2014), A Greener Earth?, Global vegetation monitoring and modelling, Avignon, France, February 3–7, 2014.

Conclusion: As CO2 is Increasing:

- Global population is becoming wealthier. Poverty is falling
- Fewer people go hungry. Malnutrition is dropping
- People are healthier and, living longer
- Deaths from extreme weather events are down
- More people have safer water & better sanitation
- Population continues to increase
- The world is greener and more productive
- Increases in agricultural and forest productivity create more space for Rest of Nature to coexist with humans

Back-up slides

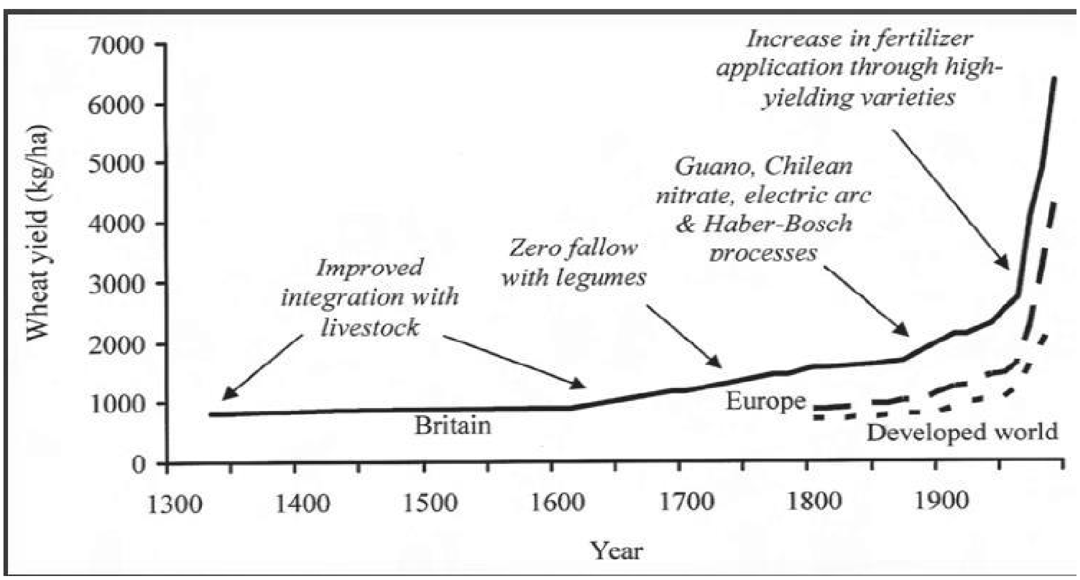
Contributions of FF to economic growth and human well-being

- Increases land productivity:
  - Increases available food
  - Reduces hunger
  - Improves health
  - Enhances human capital
- Substitutes for human and animal labor
  - Frees up human time and energy to pursue other activities
  - Enhances human capital

Contributions of FF to economic growth and human well-being

- Human capital
  - Electricity (67% worldwide from FF) “creates” more time at humanity’s disposal which allows individuals to accumulate human capital
- Bulk of new technology powered directly or indirectly by energy [81% of global energy from FF]

Agricultural Productivity, 1300–2000



Source: N. B. J. Koning, et al., "Long-term global availability of food: continued abundance or new scarcity?" NJAS Wageningen Journal of Life Sciences 55 (2008): 229–292.

Notes Summary:

Slide 3: 'Goklany IM. Humanity unbound: how fossil fuels saved humanity from nature and nature from humanity. Policy Analysis, No. 715, Cato Institute, Washington, DC (2012).'
Slide 10: 'Goklany IM. Deaths and death rates from extreme weather events: 1900-2008. Journal of American Physicians and Surgeons, 14(4), 102-109 (2009)'
Slide 12: 'LAI is a measure of how much of the area is covered by leaves'
Slide 13: 'Zhu Z and Myneni RB (2014), A greener Earth (?) Global vegetation monitoring
and modelling, Avignon, France, February 3 to 7, 2014.'
Slide 18: '1300-1800: crop rotation, 2-crop, 3-crop, 4-crop with nitrogen fixing legumes
Late 1700s –early 1900s: bones → guano (early 1800s, Humboldt) → mineral nitrates → chemical nitrogen fixation→'

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Comment
The following comments are based on a very cursory look. I may have additional comments on subsequent drafts.
"much" -- relative to what? I recommend providing numbers and contrasting that with the average temperature of the earth or similar measurefor context.
The term "dominant" seems somewhat too strong considering the state of knowledge. I'm not sure that even the IPCC uses this term. Also, this is confusing since the sentence presumably addresses "all" human activities on one hand, and "emissions of greenhouse gases" on the other. Which component does the term "dominant" apply to. I would drop this term.
Please insert "known" between "no" and "natural". There are some analyses that claim to have discovered cycles. These should be discussed. See, e.g., (1) Abbot J, Marohasy J. The application of machine learning for evaluating anthropogenic versus natural climate change. GeoResJ. 2017 Aug 5. (2) Wyatt MG, Kravtsov S, Tsonis AA. Atlantic multidecadal oscillation and Northern Hemisphere’s climate variability. Climate Dynamics. 2012 Mar 1;38(5-6):929-49.
This is based on shaky logic. See comments on Chapter 1, Row 16.
There should be discussion regarding the performance of models. Have they been validated, how do they fare relative to the short period for which observations are available and which were not used to develop the models (i.e., the out-of-sample period), etc. See Row 17, comments on Chapter 1.
Why are we discussing the 2 degree C limit? Is there a scientific or economic rationale for discussing this magical number? I would eliminate this, unless there is an analysis that supports and justifies its inclusion.
How likely is the "expected" value?
Nothing can be "ruled out" unless it contravenes a fundamental law of physics or thermodynamics. How likely is the 6 to 10 feet rise? If you can't estimate the liklehood and provide back-up, considering all the uncertainties, including model performance, historical terends in SLR, etc., I would drop the last sentence. Also, I would modify the discussion page 32 appropriately.
These pages rely on model projections. Do these projections consider and adjust for model performance?

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It should be noted that while heat waves may have become more frequent since the 1960s, the warmest temperatures and heat spells occurred during the 1930s. Also, the text should note that since coldest temperatures have also moderated it seems that temperatures are generally more moderate today than before 1970. See Figs 6.3 and 6.4 in the 5th draft of the Climate Science Special Report. I would include these figures in this chapter because they provide a more complete record, and context to major concerns related to global warming.
Is this language consistent with Figs 6.3 and 6.4 in the 5th draft of the Climate Science Special Report? This should be discussed.

While precipitation is important, the likelihood of floods and droughts are probably more critical for most people (and natural systems). The Key Message should address historical trends in drought and floods for the U.S. See: (1)McCabe GJ, Wolock DM, Austin SH. Variability of runoff-based drought conditions in the conterminous United States. International Journal of Climatology. 2017 Feb 1;37(2):1014-21. (2) Hirsch RM, Ryberg KR. Has the magnitude of floods across the USA changed with global CO2 levels?. Hydrological Sciences Journal. 2012 Jan 1;57(1):1-9. (3) Hodgkins GA, Whitfield PH, Burn DH, Hannaford J, Renard B, Stahl K, Fleig AK, Madsen H, Mediero L, Korhonen J, Murphy C. Climate-driven variability in the occurrence of major floods across North America and Europe. Journal of Hydrology. 2017 Sep 1;552:704-17.
What is the empirical evidence for trends in soil moisture? There should also be a discussion of the effect of CO2 on soil moisture and evapotranspitration. See, e.g., Keenan TF, Prentice IC, Canadell JG, Williams CA, Wang H, Raupach M, Collatz GJ. Recent pause in the growth rate of atmospheric CO2 due to enhanced terrestrial carbon uptake. Nature communications. 2016;7. In light of this (and other papers), shouldn't the "likely" statement be revisited?

There should be a Key Message devoted to whether and by how much the U.S, Alaska and the globe have greened (or not), as well as a discussion of the possible causes and effects. See: (1) Li P, Peng C, Wang M, Li W, Zhao P, Wang K, Yang Y, Zhu Q. Quantification of the response of global terrestrial net primary production to multifactor global change. Ecological Indicators. 2017 May 31;76:245-55. (2) Zhu Z, Piao S, Myneni RB, Huang M, Zeng Z, Canadell JG, Ciais P, Sitch S, Friedlingstein P, Arneth A, Cao C. Greening of the Earth and its drivers. Nature climate change. 2016 Apr 25.
There should be a Key Message and discussion of long term empirical trends in strong and weak hurricanes and tornadoes.
There should be discussion of the portion of such increased flooding due to various factors (e.g., greenhouse gas induced warming, subsidence, built-up pavements, etc.) and how they might be apportioned.

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(1) Nothing can be "ruled out" unless it contravenes a fundamental law of physics or thermodynamics. How likely are these changes? Without an estimate of likelihood or even confidence in such claims, this is meaningless. (2) The claim that models systematically underestimate temperature change contradicts the fact that climate models may have overstated the rate of warming (IPCC AR5 WG1, page 768, Box 9.2; Fyfe etal. 2013; Fyfe et al. 2016; Santer et al. 2017).

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Comment
The writing of this chapter should be deferred until the rest of the document has crystallized and in better shape. In addition, it has several flaws, as noted in the following, that ought to be fixed.
This chapter lacks context. In particular, it should note that any climate change that is occurring is happening against a backdrop of a society that is becoming wealthier, more technologically advanced and adaptable, directly or indirectly in part due to activities that may be fuelling that climate change, as evidenced, for example, by long term increases in food production and life expectancies, and declines in rates of hunger, poverty, and deaths and diseases from various climate-sensitive factors (e.g., malaria, extreme weather events). It should also note that because climate change is more likely to exacerbate current/existing problems rather than create brand new ones, humanity already has a suite of adaptation options available to it to cope with climate change which, moreover, should become more effective and affordable as populations become wealthier and technologies advance. Further, it should note that over periods of decades "autonomous" adaptation has been shown to have improved various climate-sensitive indicators of human well-being by one or more order of magnitude: consider, e.g., drop in death rates from malaria and extreme weather events and poverty rates, and increases life expectancy and per capita GDP, etc. Much of the information to back up the above claims has been collected and made available as a slide presentation, which will be forwarded as a seperate file. The data sources used for the collection, which are publicly available, are cited, in case one needs to undertake due diligence in verifying the information. See, e.g. (1) Goklany IM. The improving state of the world: why we're living longer, healthier, more comfortable lives on a cleaner planet. Cato Institute; 2007. (2) Goklany IM. Have increases in population, affluence and technology worsened human and environmental well-being. The Electronic Journal of Sustainable Development. 2009;1(3):15. (3) Goklany IM. Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development. Mitigation and Adaptation Strategies for Global Change. 2007 Jun 1;12(5):755-86. (4) Goklany IM. Deaths and death rates from extreme weather events: 1900-2008. Journal of American Physicians and Surgeons, 14(4), 102-109 (2009).

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Many, if not most, people reading this document would, based on my experience, tend to conflate "climate change" with "greenhouse gas induced anthropogenic climate change" and would not distinguish changes resulting from natural variability in the weather from either greenhouse gas induced CC, other anthropogenic factors, or natural changes in climate. Accordingly, for the reader's sake, the chapter (and indeed the whole document) should be careful to make these distinctions. For example, when an observed impact is under discussion, the discussion should strive to apportion impacts into its constituent causes and make these distinctions or acknowledge that they cannot or have not been made (at least as yet).
The document needs to distinguish between -- and where possible -- apportion changes in observed impacts to the various factors affecting those impacts, including variability in the weather, natural climate change, anthropogenic climate change, as well as various anthropogenic factors other than greenhouse gases can contribute to climate change. For example, on Chapter 1, p. 8, lines 5-6, it is stated, "The impacts of climate change are already underway in the United States…" It's not clear how the impacts of CC were distinguished from the impacts of just variability in the weather. Nor does it distinguish the portion of impacts caused by, say, greenhouse gas induced warming from other anthropogenic factors (see, e.g., comment on forest fire damage below). The document needs to make and justify these distinctions, or alternatively note that these distinctions cannot (yet) be made. In the absence of such information the reader may be misled into thinking the entire change may be attributable to greenhouse gas emissions. I would recommend a couple of paragraphs at the beginning of this chapter in the overview clarifying and explaining this to the readers.
It should be noted that that the "frequent flooding" may be due to non-climatic factors such as subsidence from a variety of causes, and construction of impervious surfaces. In some instances, it may be a perception driven by the fact that more people have, for whatever reason, built on flood zones, etc.
The term, "rising" needs to be placed in context. Specifically, it should be noted that data from the Historical Statistics of the United States and the National Interagency Fire Center indicates that wildland fires burned 4 to 5 times as much acreage annually in the 1930s and 1940s than since 2000. Sources: https://fraser.stlouisfed.org/files/docs/publications/histstatus/hstat1970_cen_1975_v1.pdf; https://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html
The list of factors contributing to "rising forest fire damage" is incomplete, at best. It should be noted that "Humans have vastly expanded the spatial and seasonal 'fire niche' in the coterminous United States, accounting for 84% of all wildfires and 44% of total area burned." [Source: Balch JK, Bradley BA, Abatzoglou JT, Nagy RC, Fusco EJ, Mahood AL. Human-started wildfires expand the fire niche across the United States. Proceedings of the National Academy of Sciences. 2017 Mar 14;114(11):2946-51.] It should also be noted that management practices also affect the number and acreage of burned areas.

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It's not clear that the entire west is suffering from "severe drought." In fact, because of "weather" alone, one should expect some drought in one portion or another in the U.S. in any given year. See: McCabe GJ, Wolock DM, Austin SH. Variability of runoff-based drought conditions in the conterminous United States. International Journal of Climatology. 2017 Feb 1;37(2):1014-21.
This is based on bad logic. I believe, some logicians would label this "argument from ignorance". It assumes that because the authors cannot come up with another explanation no alternative explanation exists. It also assumes we know everything about natural factors that can influence climate including the factors themselves, how strong they are, how they evolve, etc. Equally importantly, the fact that climate models may have overstated the rate of warming (IPCC AR5 WG1, page 768, Box 9.2; Fyfe etal. 2013; Fyfe et al. 2016; Santer et al. 2017) implies that we know less than we think we do, and natural factors may be more important than they are given credit for. So my recommendation on this is either re-do this completely or present the alternative point of view I have stated.
Since a substantial portion of the report reports on projected climatic factors, there should be discussion in the Overview about the performance of models used to make these projections. This discussion should at a minimum, address whether these models have been validated, how well do the models track observations in the “out-of-sample” period, i.e., the period which does not overlap the historical period used to formulate and fine tune the model and for which observations are available. This should be done for the globe as well as the U.S. and its subregions. And it should address both temperature and precipitation, and the rates of changes in these climatic variables at different scales.
This is a conclusion that should await the finalization of the rest of the document. Also, it is not clear that, as a general matter, the impacts of climate change are intensifying in terms of adverse effects on human health and general well-being because, as noted in previous comments, because we are living longer, healthier and wealthier, among other things. See comments on Row 9.
Is there a chapter on benefits-cost analysis that supports the statement, "over time costs will greatly outweigh the benefits"? Absent such a chapter, please remove or modify this statement, providing appropriate references, etc.
I may have missed it, but I don't see any benefit-cost analysis in the document that supports the statement, "There is a strong economic case for reducing the risks of climate change by cutting greenhouse gas emissions." Please remove or modify this statement, providing appropriate references, etc.

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It should be noted that the cost of any efforts to reduce anthropogenic climate change may also weigh heavily on disadvantaged populations. It may, for example, increase the costs of energy which, in turn, would increase cost of food, transportation, heating and cooling, etc., which are essential for survival, especially for the disadvantaged, and would reduce their disposable income, which then would make it harder for them to cope with all of life's exigencies, not only those related to climate or climate change. So it doesn't necessarily follow that reducing the risks of climate change will offset the risks themselves. In fact, it may excerbate the ability to cope with other risks. See: Goklany IM. Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development. Mitigation and Adaptation Strategies for Global Change. 2007 Jun 1;12(5):755-86.
"Observations" cannot show definitively or otherwise what the cause of the observation is. That has to be inferred or deduced by other means. Given that CMIP5 models are having difficulty reproducing observations (see comments in Row 16) outside of the period used to develop (and fine tune) the models, I would be wary of using the term, "definitive."
1. I would extend the time period covered by the figure to include a comparison of temperatures between "observed" and "all drivers" through the latest date possible (for publication), which presumably would be some time next year. 2. Also, there should be discussion regarding why we are using one rather than another data set for temperatures. 3. Since the NCA is for the United States, there should be a similar figure for the U.S. If there is a premium on space, it would be appropriate to include a figure just for the U.S. 4. There should be similar figures for precipitation.
We need to put warming in context. It should be noted that while temperatures continue to rise, so does human well-being, including those indicators of well-being that are climate-sensitive: food production is up, hunger is down, people are living longer and healthier, deaths from extreme weather events are down, and people are also wealthier. In large part, the improvements in human well-being may be due to economic growth sustained through the current energy system which, moreover, would help make societies more resilient and adaptable. Moreover, these improvements also increase our ability to adapt and cope with climate change. Source: (1) Goklany IM. Is climate change the number one threat to humanity?. Wiley Interdisciplinary Reviews: Climate Change. 2012 Nov 1;3(6):489-508. (2) See comments and references provided in Row 9.
While "Heat waves have become more frequent since the 1960s", it should be also noted that (a) the warmest temperatures and heat spells occurred during the 1930s and exceeded current levels preceding 1960, (b) coldest temperatures have moderated, and (c) overall the temperatures are generally more moderate today than before 1970. See Figs 6.3 and 6.4 in the 5th draft of the Climate Science Special Report. I would include these figures in this chapter because they provide a more complete record, and context to major concerns related to global warming.

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1. Overview / Executive Summary		15	18
1. Overview / Executive Summary		15	38
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1. Overview / Executive Summary		17	24
1. Overview / Executive Summary		17	24
1. Overview / Executive Summary		18	1
1. Overview / Executive Summary		19	3

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18	2
19	3

1. The text should also note whether the changes that it claims "will" happen have, in fact, occurred over the past century or so, a period of global warming. Are droughts actually longer and more intense in the U.S. (in general)? Is the empirical record consistent with what should be expected uncer increased warming? It should add that in "other places there may be fewer droughts or less heavy rainfall". 2. While it's OK to talk about extreme precipitation, it would be more appropriate from the point of view of human and ecological well-being to discuss floods and droughts. What does the empirical record show regarding their trends, particularly for the U.S.? See: (1) McCabe GJ, Wolock DM, Austin SH. Variability of runoff-based drought conditions in the conterminous United States. International Journal of Climatology. 2017 Feb 1;37(2):1014-21. (2) Hirsch RM, Ryberg KR. Has the magnitude of floods across the USA changed with global CO2 levels?. Hydrological Sciences Journal. 2012 Jan 1;57(1):1-9. (3) Hodgkins GA, Whitfield PH, Burn DH, Hannaford J, Renard B, Stahl K, Fleig AK, Madsen H, Mediero L, Korhonen J, Murphy C. Climate-driven variability in the occurrence of major floods across North America and Europe. Journal of Hydrology. 2017 Sep 1;552:704-17.
The text should note that oxygen losses may occur for a variety of reasons other than climate/CC, and list some of these factors.
The text should note that flooding may occur for a variety of reasons other than climate/CC, and list some of these factors.
1. The implicit assumption here is that the increase in risk to human and natural systems due to increased emissions necessarily outweighs the benefits resulting from the activities that generate those emissions. The information furnished along with comments on Row 9 suggest that many, if not, most climate-sensitive risks are declining faster than they are increasing, for whatever reason. Also, there is no benefit-cost analysis provided to support this text in the Overview. Where is that analysis in this document? 2. Reductions in emissions make sense if benefits of reductions exceed costs. Also, that analysis is also missing. I recommend removing this paragraph.
Without discussion of the costs of emission reductions, and the uncertainties associated not only with modeling the rate of climate change, its impacts, etc., this section is misleading. Estimates of the range of impacts should consider not only the spread due to using various scenarios but the cumulative range implied by the methodologies employed, including uncertainties in inputs, assumptions, etc.
Why are we discussing "Rising Temperatures and Heat Waves" once again? This was discussed earlier on p. 14. See the comments above.
A number of topics addressed here duplicate topics addressed previously. Pl redress this.
A number of topics addressed here duplicate topics addressed previously. Pl redress this.
Please (1) Add the range of global average surface ocean pH, and the range by which pH would increase, (2) Considering that the surface ocean is slightly basic, it is inaccurate to say that acidity will increase rather than state that the ocean surface would be more neutral , (3) Specify the range of natural variability in pH at any location and from location-to-location.

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1. Overview / Executive Summary		18	13
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19	2
19	31
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21	2
21	9
22	27

"Acidification" and "increase in acidity" are technically inaccurate (even if they evoke emotional responses in readers) since you can't have more acidity unless one has acidic water in the first place. Considering that average ocean pH is around 8, it would much more accurate to say that additional CO2 absorption would make the ocean more neutral -- so "ocean neutralization" would be more accurate than "ocean acidification" . The USGCRP, a scientific research program, ought to use terms that are more precise and accurate. See above comment.
The notion that one can have a high emissions scenario with high impacts but no adaptation contradicts virtually all human experience. In fact, even before people were concerned about the impacts of global warming, they adapted. Because of such adaptation, death rates from malaria, water-borne diseases, and extreme weather events are more than 90% below what they used to be, we have greater access to cleaner water, life expectancies are up, etc. See, comments on Row 9, and information furnished in conjunction with that. Either drop this paragraph or discuss it in greater depth. Regardless, the individual chapters that provide impact estimates without fully considering autonomus adaptation must discuss this matter, and its effect on impact estimates. In addition, for every impact estimate that is furnished, there should be discussion of the cumulative uncertainty/confidence in the results of the impact analyses considering uncertainty/confidence not only in the GCMs but also all other factors feeding into that estimate. See: (1) Goklany IM. Is climate change the number one threat to humanity?. Wiley Interdisciplinary Reviews: Climate Change. 2012 Nov 1;3(6):489-508. (2) Goklany IM. Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development. Mitigation and Adaptation Strategies for Global Change. 2007 Jun 1;12(5):755-86.
Given that "NCA4 does not assess the adequacy of existing or planned mitigation efforts relative to meeting specific policy targets, nor does it describe, evaluate, or recommend policy options." (page 20, lines 9-10), I recommend dropping this entire section.
It should be noted that renewable solar and wind energy generation is thriving because they are effectively subsidized directly or indirectly via various policy mandates, and that they too have impacts on wildlife and land use.
It should be noted that: (1) many co-benefits may be obtained more cheaply through means other than mitigation (or emission reduction). In fact, this is the general experience for most developed countries with respect to air pollution. It may, therefore, be more cost-effective to go that route than attempt to change the entire energy system. See the references provided on Row 36. (2) There are costs in terms of reliability and lack of access to electricity 24/7/365 associated with these alternative generation methods, as well environmetal costs such as increased land use and impacts on birds and other avian species.
There should be a broader discussion of adaptation. See comments on Rows 9, 21, 24 and 36.

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1. Overview / Executive Summary			
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8	36

There needs to be discussion of whether and by how much the U.S, Alaska and the globe have greened (or not), as well as a discussion of the possible causes and effects. In fact, the paragraphs on page 205, lines 5-11, and lines 17-18 should be incorporated into the Overview and Chapter 2. This should be a key finding. See also: Li P, Peng C, Wang M, Li W, Zhao P, Wang K, Yang Y, Zhu Q. Quantification of the response of global terrestrial net primary production to multifactor global change. Ecological Indicators. 2017 May 31;76:245-55.
While I appreciate why anomalies are presented in many figures, there is a substantial loss of context when only anomalies are provided. Consider, for example, Figure 1.4: Many readers will have no idea what the magnitude of projected change would be relative to the baseline temperatures. I would recommend that to help them visualize the relative magnitude of change, that a figure should be presented that would show the total temperature profile with and without climate change. Providing anomalies without also providing the baseline information can mislead many a reader, and the whole purpose of writing reports is to inform.
In light of the above comment, the appropriate modifications should also be made to the text.
Sea level rise should be placed into its long term context. It should be noted that sea levels have risen about 400 feet since the last ice age.
It's not clear whether application of this table would necessarily result in reproducible results if the composition of the group is changed. Has the methodology been tested using different groups and reproducibility verified? This should be discussed.
There should be a discussion, with graphs, of long term trends in weak and strong hurricanes landfalling in the U.S., accumulated cyclone energy, and tornados. See: Maue, R. N. (2011), Recent historically low global tropical cyclone activity. , Geophys. Res. Letts. VOL. 38, L14803, 6 PP., 2011 doi:10.1029/2011GL047711
Considering that the observed rate of global warming is substantially below CMIP5 projections for the recent decades (see Row 16), a fresh look at alternative hypotheses/models would be warranted. There should be frank discussion of this issue, presenting all sides of the arguments for the various hypotheses.. Would recommend a box for that discussion. See, e.g., (1) Abbot J, Marohasy J. The application of machine learning for evaluating anthropogenic versus natural climate change. GeoResJ. 2017 Aug 5. (2) Wyatt MG, Kravtsov S, Tsonis AA. Atlantic multidecadal oscillation and Northern Hemisphere's climate variability. Climate Dynamics. 2012 Mar 1;38(5-6):929-49.

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The notion that one can have a high emissions scenario with high impacts but no adaptation contradicts virtually all human experience. In fact, even before people were concerned about the impacts of global warming, they adapted. Because of such adaptation, death rates from malaria, water-borne diseases, and extreme weather events are more than 90% below what they used to be, we have greater access to cleaner water, life expectancies are up, etc. See, comments on Row 9, and information furnished in conjunction with that. Either drop this paragraph or discuss it in greater depth. Regardless, the individual chapters that provide impact estimates without fully considering autonomus adaptation must discuss this matter, and its effect on impact estimates. In addition, for every impact estimate that is furnished, there should be discussion of the cumulative uncertainty/confidence in the results of the impact analyses considering uncertainty/confidence not only in the GCMs but also all other factors feeding into that estimate. See: (1) Goklany IM. Is climate change the number one threat to humanity?. Wiley Interdisciplinary Reviews: Climate Change. 2012 Nov 1;3(6):489-508. (2) Goklany IM. Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development. Mitigation and Adaptation Strategies for Global Change. 2007 Jun 1;12(5):755-86. (3) Heutel G, Miller NH, Molitor D. Adaptation and the Mortality Effects of Temperature Across US Climate Regions. National Bureau of Economic Research; 2017 Mar 23.
"Acidification" and "increase in acidity" are technically inaccurate since you can't have more acidity unless one has acidic water in the first place. Considering that average ocean pH is around 8, it would much more accurate to say that additional CO_2 absorption would make the ocean more neutral -- so "ocean neutralization" would be more accurate than "ocean acidification" . The USGCRP, a scientific research program, ought to strive use terms that are more precise and accurate.
Karl et al. (2015) and Mears and Wentz (2016) indicate that empirical data sets need to be adjsuted to account for various artifacts. If that's the case, have the authors of this document considered whether and how these adjustments may affect results derived by studies predating them? Might this affect the parameters employed in the models, and their performance, etc.? Might that affect projections regarding the rate of warming, and so forth? I recommend a box, at a minimum, discussing this, and related matters.

CommentTypes	ChapterTitles
Whole Document	Full Second Order Draft
Whole Chapter	Front Matter
Whole Page	1. Overview / Executive Summary
Text Region	2. Our Changing Climate
Figure	3. Water
Table	4. Energy
Traceable Account	5. Land Cover and Land Use Change
	6. Forests
	7. Ecosystems, Ecosystem Services, and Biodiversity
	8. Coastal Effects
	9. Oceans and Marine Resources
	10. Agriculture and Rural Communities
	11. Built Environment, Urban Systems, and Cities
	12. Transportation
	13. Air Quality
	14. Human Health
	15. Tribal and Indigenous Communities
	16. Climate Effects on U.S. International Interests
	17. Sectoral Interdependencies and Compounding Stressors
	18. Northeast
	19. Southeast
	20. US Caribbean
	21. Midwest
	22. Northern Great Plains
	23. Southern Great Plains
	24. Northwest
	25. Southwest
	26. Alaska
	27. Hawai'i and Pacific Islands
	28. Near-Term Adaptation Needs and Increased Resiliency
	29. Mitigation: Avoiding and Reducing Long-Term Risks
	Appendix 1: Process
	Appendix 2: Information Quality Act
	Appendix 3: Data Tools and Scenario Products
	Appendix 4: International
	Appendix 5: Frequently Asked Questions

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From: Linford, Brooke
Sent: 2017-09-05T08:03:36-04:00
Importance: Normal
Subject: EKIP Redemption Report for 9/1/2016 - 8/31/2017
Received: 2017-09-05T08:04:00-04:00
EKIP Redemption Data 9-1-2016 - 8-31-2017.xlsx

Hello everyone,
Attached is the final EKIP Redemption Report for the 2016/2017 school year. There was a 50% increase over 2015/2016! Please let me know if you have any comments or questions.
Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1849 C Street, NW
Room 2345
Washington, DC 20240

Phone: 202-513-7139

Every Kid in a Park 4th Grade Pass

Reported in Redemption Site 9/1/2016 - 8/31/2017

FOR INTERNAL USE ONLY

Grand Total	**198,524**
BLM	**11,474**
Idaho BLM Office	2,958
Red Rock Canyon National Conservation Area BLM	1,431
California BLM Office	1,250
National Historic Trails Interpretive Center	756
BLM Eastern States Office	687
Idaho State Office - BLM	619
Colorado BLM Office	570
Red Rock Canyon National Conservation Area - BLM	549
Eagle Lake BLM Field Office	351
Eastern States BLM Field Office	297
Pompeys Pillar Interpretive Center - BLM	256
BLM Prineville Office	249
Klamath Falls Resource Area	207
Gunnison Gorge National Conservation Area	204
Redding BLM Field Office	192
Palm Springs - South Coast BLM Field Office	144
Ukiah BLM Field Office	134
Nevada BLM Office	102
Alturas BLM Field Office	99
Coos Bay BLM District Office	69
Yaquina Head Oustanding Natural Area	66
Rio Puerco BLM Field Office	59
Casper Field Office - BLM	58
Arizona Strip District Office (in Utah)	54
BLM Medford Office	54
Miles City BLM Office	13
Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument)	13
Spokane BLM Office	9
Royal Gorge BLM Field Office	4
Utah BLM Office	4
Grand Junction BLM Field Office	3
Rock Springs Field Office - BLM	3
Wyoming BLM Office	2
Arizona BLM State Office	2
Richfield BLM Field Office	2
Las Vegas BLM Field Office	2

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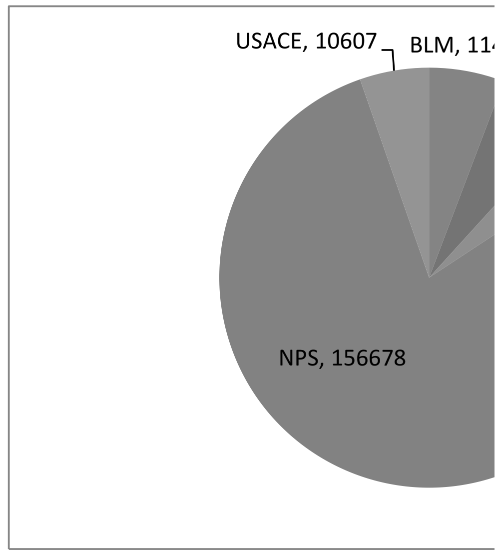
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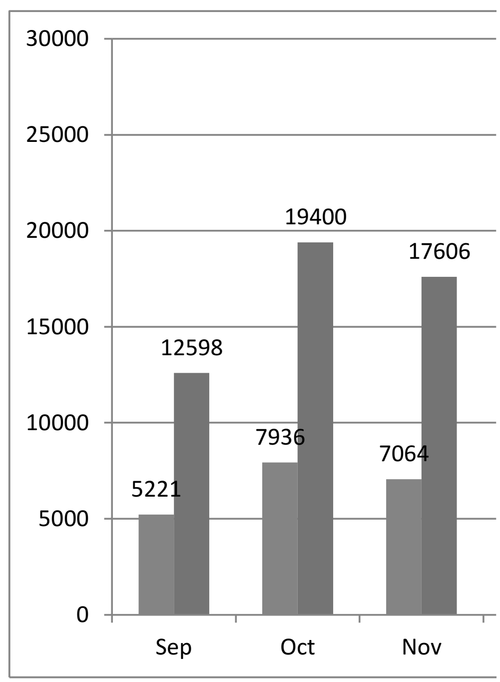
BLM, 11
NPS, 156678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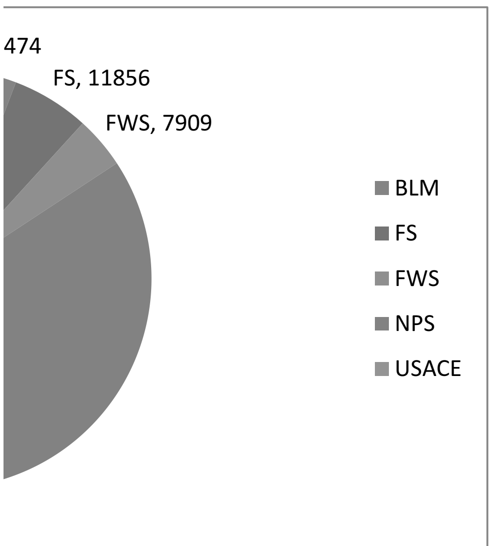

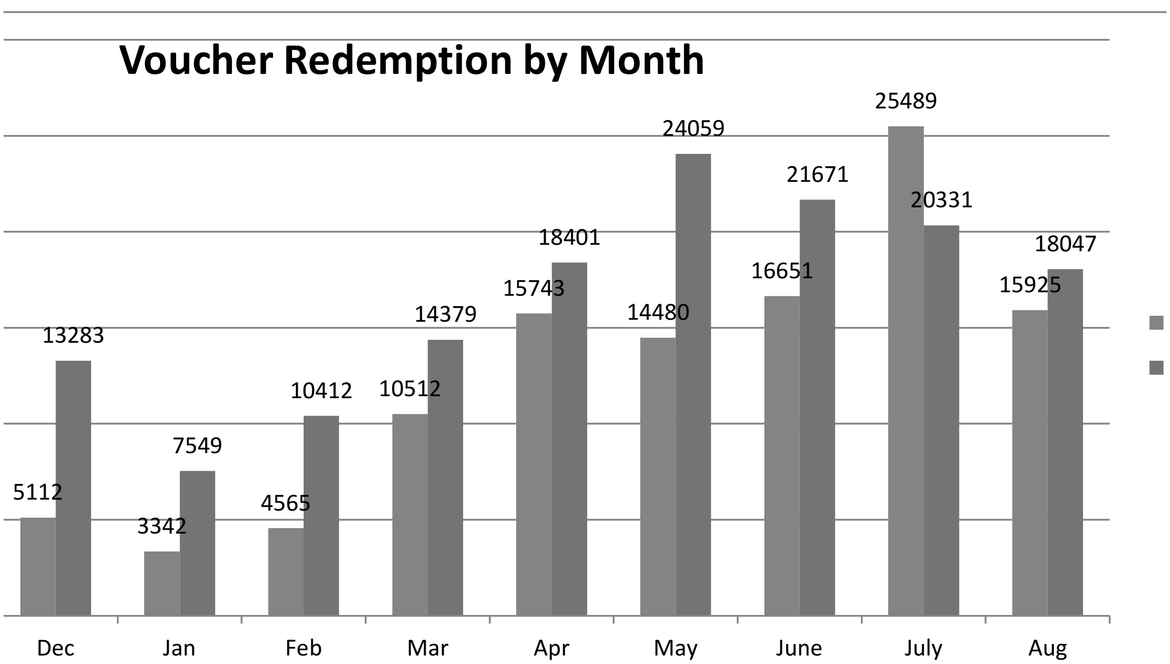

2015/2016

2016/2017

Kremmling BLM Field Office	1
Eugene District BLM Office	1
FS	**11,856**
Land Between the Lakes	807
Apache-Sitgreaves NF - Lakeside District	734
Stanislaus NF - Mi-Wok District	500
Lewis & Clark NF - Main Office	484
Uinta-Wasatch-Cache NF - Pleasant Grove District	421
US Forest Service Region 9	407
Chugach National Forest	405
Lincoln NF - Sacramento District	397
Rogue River - Siskiyou NF - Main Office	368
Tongass NF - Mendenhall Glacier Visitor's Center	368
Okanogan-Wenatchee NF - Cle Elum District	363
Washington & Jefferson NF - Lee District	356
Umpqua NF - Main Office	340
Mount St. Helens National Volcanic Monument	324
Caribou-Targhee NF - Ashton/Island Park District	301
Cibola NF - Main Office	292
Fremont-Winema NF - Main Office	248
US Forest Service Regional Office	238
Ottawa NF - Visitor Center	228
San Bernardino NF - Mountaintop District - Big Bear Ranger Station	184
Umpqua NF - Diamond Lake Visitor Center	181
Mt Hood NF - Hood River District	178
White Mountain NF - Main Office	169
Gifford Pinchot NF - Main Office	160
Tongass NF - Southeast Alaska Discovery Center	154
Coconino NF - Red Rock Visitor's Center	137
Mt Hood NF - Zigzag District	121
Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District	111
Ocala NF - Lake George District	110
Bighorn NF - Powder River District	109
Apache-Sitgreaves NF - Springerville District	109
Apache-Sitgreaves NF - Alpine District	109
Caribou-Targhee NF - Dubois District	107
Olympic NF - Main Office	103
Pike & San Isabel NF - South Platte District	101
Shawnee NF - Mississippi Bluffs District	94
Coconino NF - Red Rock District	90
Eldorado NF - Main Office	89
Allegheny NF - Bradford District	88
Tahoe NF - Main Office	80
San Bernardino NF - Main Office	74
Carson NF - Main Office	71

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Malheur NF - Emigrant Creek District	69
San Bernardino NF - Front Country District - Cajon Ranger Station	63
Outdoor Recreation Information Center - Seattle Flagship REI Store	62
Okanogan-Wenatchee NF - Tonasket District	60
Arapahoe & Roosevelt NF - Clear Creek District	59
Clearwater NF - Main Office	55
White River NF - Blanco District	51
Umpqua NF - North Umpqua District	51
Chequamegon-Nicolet NF - Main Office	44
Colville NF - Republic District	40
Coronado NF - Main Office	39
Mt Baker/Snoqualmie NF - Snoqualmie District	37
Bighorn NF - Main Office	37
Uinta-Wasatch-Cache NF - American Fork Fee Station	33
Black Hills NF - Mystic District	32
Apache-Sitgreaves NF - Supervisor's Office	32
Shasta-Trinity NF - Main Office	29
Gifford Pinchot NF - Mt Adams District	27
Tonto NF - Mesa District	24
Humboldt-Toiyabe NF - Bridgeport District	24
Uinta-Wasatch-Cache NF - Heber-Kamas District	23
Tonto NF - Main Office	23
Sequoia NF - Main Office	21
Prescott NF - Bradshaw District	20
Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District	20
Fishlake NF - Fillmore District	17
Deschutes NF - Bend/Fort Rock District	17
Carson NF - El Rito Station	17
Sequoia NF - Kern River District - Lake Isabella Office	17
Humboldt-Toiyabe NF - Main Office	16
Kaibab NF - North Kaibab District	15
Bridger-Teton NF - Pinedale District	14
Manti-La Sal NF - Sanpete District	14
Sawtooth NF - Fairfield District	13
Tonto NF - Cave Creek District	12
Mt Baker/Snoqualmie NF - Enumclaw Office	12
Caribou-Targhee NF - Westside District	12
Idaho Panhandle NF - Coeur d'Alene River District	11
Santa Fe NF - Main Office	11
Apache-Sitgreaves NF - Black Mesa District	11
Black Hills NF - Main Office	10
Coconino NF - Main Office	10
Coronado NF - Santa Catalina District	9
Siuslaw NF - Main Office	9
Olympic NF - Pacific District	9

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Sawtooth NF - Main Office	9
Pike & San Isabel NF - Salida District	9
Arapahoe & Roosevelt NF - Boulder District	8
Manti-La Sal NF - Main Office	8
Six Rivers NF - Mad River District	8
Fishlake NF - Main Office	8
Flathead NF - Tally Lake District	8
San Bernardino NF - San Jacinto District	7
Kaibab NF - Williams District	7
Arapahoe & Roosevelt NF - Canyon Lakes District	7
Sawtooth NF - Minidoka District	6
Bighorn NF - Medicine Wheel/Paintrock District	6
Fishlake NF - Fremont River District	6
Coconino NF - Mogollon Rim District	6
Prescott NF - Chino District	5
Arapahoe & Roosevelt NF - Sulphur District	5
Okanogan-Wenatchee NF - Main Office	5
Nebraska National Forest - Pine Ridge District	5
Kaibab NF - Main Office	5
Umatilla NF - Walla Walla District	5
Caribou-Targhee NF - Palisades District	5
Cleveland NF - Trabuco District	5
White River NF - Dillon District	5
Uinta-Wasatch-Cache NF - Evanston District	4
Colville NF - Newport District	4
Uinta-Wasatch-Cache NF - Logan District	4
White Mountain NF - Saco District	4
Willamette NF - McKenzie River District	4
Gifford Pinchot NF - Cowlitz Valley District	3
Hoosier National Forest	3
Caribou-Targhee NF - Montpelier District	3
Malheur NF - Main Office	3
Wallowa-Whitman NF - Main Office	3
Inyo NF - Mammoth Lakes Center	3
Klamath NF - Scott River & Salmon River Districts	3
Klamath NF - Main Office	3
Payette NF - McCall District	3
Rogue River - Siskiyou NF - Wild Rivers District	3
Angeles NF - Main Office	3
Nebraska NF - Wall District	3
Rogue River - Siskiyou NF - Powers District	3
Humboldt-Toiyabe NF - Carson District	3
Okanogan-Wenatchee NF - Entiat District	3
Crooked River National Grasland	3
Green Mountain NF - Middlebury Station	3

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Mt Hood NF - Clackamas River District	3
Idaho Panhandle NF - Main Office	2
Umatilla NF - Main Office	2
San Juan NF - Dolores District	2
Shasta-Trinity NF - Shasta Lake Station	2
Rogue River - Siskiyou NF - High Cascades District	2
Ashley NF - Flaming Gorge District	2
Mt Baker/Snoqualmie NF - Darrington District	2
Nez Perce NF - Main Office	2
Coronado NF - Douglas District	2
Black Hills NF - Bearlodge District	2
Okanogan-Wenatchee NF -Wenatchee River District	2
Okanogan-Wenatchee NF - Naches District	2
Dakota Prairie Grasslands - Medora District	2
Fishlake NF - Beaver District	2
Rogue River - Siskiyou NF - Gold Beach District	2
Helena NF - Lincoln District	2
Helena NF - Helena District	2
Kaibab NF - Tusayan District	2
Beaverhead-Deerlodge NF - Main Office	2
San Bernardino NF - Front Country District - San Gorgonio Ranger Station	2
Medicine Bow NF - Brush Creek/Hayden District	2
Routt NF - Parks Walden District	2
Willamette NF - Detroit District	2
Sawtooth NF - Ketchum District	2
Mendocino NF - Main Office	2
Ozark - St. Francis NF - Main Ofiice	1
Rio Grande NF - Divide District	1
Siuslaw NF - Hebo District	1
Umpqua NF - Cottage Grove District	1
Sierra NF - High Sierra District	1
Idaho Panhandle NF - St. Joe District	1
Nebraska National Forest - Bessey District	1
Lincoln NF - Guadalupe District	1
Croatan NF - Main Office	1
Mendocino NF - Upper Lake District	1
Huron-Manistee NF - Cadillac/Manistee District	1
Payette NF - New Meadows District	1
Sam Houston NF	1
San Juan Public Lands Center - FS	1
San Juan NF - Pagosa District	1
Colville NF - Three Rivers District	1
Rogue River - Siskiyou NF - Siskiyou Mountains District	1
Gallatin NF - Hebgen Lake District	1
Dakota Prairie Grasslands - Main Office	1

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

Shasta-Trinity NF - Mount Shasta Station	1
Ozark - St. Francis NF - Sylamore Mountain District	1
Angeles NF - San Gabriel River District	1
Mt Baker/Snoqualmie NF - Mt Baker District	1
Shasta-Trinity NF - Weaverville Station	1
Rio Grande NF - Conejos Peak District	1
Siuslaw NF - Waldport Office	1
Sierra NF - Oakhurst Office	1
Six Rivers NF - Orleans District	1
Medicine Bow NF - Main Office	1
Grey Towers National Historic Site	1
Routt NF - Yampa District	1
Sierra NF - Main Office	1
Black Hills NF - Hell Canyon District	1
Green Mountain NF - Main Office	1
US Forest Service in Mississippi - Main Office	1
Routt NF - Hahans Peak/Bears Ears District	1
Ozark - St. Francis NF - Boston Mountain District	1
Ashley NF - Duchesne District	1
Cherokee NF - Nolichucky/Unaka District	1
Grand Mesa, Uncompahgre, & Gunnison NF	1
Sawtooth NF - Stanley District	1
Los Padres NF - Main Office	1
Nantahala NF - Highlands District	1
FWS	**7,909**
J.N. "Ding" Darling National Wildlife Refuge	3,132
Arthur R. Marshall Loxahatchee NWR	1,370
Nisqually NWR	845
Two Rivers National Wildlife Refuge	415
Sam D. Hamilton Noxubee NWR	392
Hobe Sound NWR Nature Center (also sold at fee booth)	350
Back Bay NWR	329
Bombay Hook National Wildlife Refuge	218
St. Marks National Wildlife Refuge	164
Chincoteague NWR	158
Assabet River NWR	106
Okefenokee NWR	105
Merritt Island National Wildlife Refuge	83
DeSoto National Wildlife Refuge	72
Neosho National Fish Hatchery	40
Sacramento NWR	37
National Elk Refuge	32
Fish and Wildlife Service Regional Office	18
Don Edwards San Francisco Bay NWR	9

4.0%

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

Parker River National Wildlife Refuge	8
Rocky Mountain Arsenal NWR	4
Edwin B. Forsythe NWR	4
Long Island NWR Complex	4
Bosque del Apache NWR	3
Ottawa National Wildlife Refuge	3
Deer Flat NWR	2
Blackwater NWR	2
Ridgefield NWRC	1
Seney National Wildlife Refuge	1
Laguna Atascosa NWR	1
Muscatatuck National Wildlife Refuge	1
NPS	**156,678**
San Juan National Historic Site	7,816
Yellowstone National Park	6,019
Yosemite National Park	5,824
Assateague Island National Seashore	5,257
Grand Canyon National Park	5,027
Zion National Park	4,792
Fort McHenry National Monument	4,743
Hopewell Culture National Historical Park	4,500
Chesapeake & Ohio Canal NHP	4,482
Lake Mead National Recreation Area	4,347
Colonial National Historical Park	4,230
Badlands National Park	3,943
Rocky Mountain National Park	3,766
Cuyahoga Valley National Park	3,757
Great Falls Park	3,756
Channel Islands National Park	3,713
Acadia National Park	3,280
Indiana Dunes National Lakeshore	2,865
Mount Rainier National Park	2,712
Garfield National Historic Site	2,575
Sequoia & Kings Canyon National Park	2,338
Arches National Park	2,306
Chamizal National Memorial	2,272
Lewis & Clark National Historical Park	2,126
Joshua Tree National Park	1,995
Grand Teton National Park	1,881
Glacier National Park	1,656
Richmond National Battlefield Park	1,564
Bryce Canyon National Park	1,413
Golden Gate NRA - Muir Woods Visitors Ctr	1,276
Crater Lake National Park	1,275

78.9%

Includes NAMA

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

Tumacacori National Historical Park	1,257
Delaware Water Gap National Rec Area	1,201
San Francisco Maritime National Historical Park	1,194
Pictured Rocks National Seashore	1,181
Fort Vancouver National Historic Site	1,156
Pinnacles National Monument	1,136
Petrified Forest National Park	1,113
Bents Old Fort Historic Site	1,112
Petroglyph National Monument	1,102
Harpers Ferry National Historical Park	1,098
Sleeping Bear Dunes National Lakeshore	1,072
Lowell National Historical Park	1,053
Walnut Canyon National Monument	1,039
Catoctin Mountain Park	960
Olympic National Park	953
Mesa Verde National Park	950
Colorado National Monument	876
Death Valley National Park	873
Amistad National Recreation Area	864
Appomattox Court House Historical Park	847
Montezuma Castle National Monument	831
Cedar Breaks National Monument	803
Carlsbad Caverns National Park	735
Hawaii Volcanoes National Park	692
Blue Ridge Parkway (Campgrounds)	688
Cumberland Island National Seashore	685
Wright Brothers National Memorial	665
Big Thicket National Preserve	652
Pu'uhonua O Honaunau	650
Joshua Tree National Park	646
Cabrillo National Monument	619
Canyonlands National Park	579
Castillo de San Marcos National Monument	569
Casa Grande Ruins National Monument	547
Everglades National Park	518
Little Rock Central High School NHS	517
Dinosaur National Monument (Passes only sold at UT location))	517
Great Sand Dunes National Park	497
Devils Tower National Monument	491
Capulin Volcano National Monument	476
Ulysses S Grant National Historic Site	467
Organ Pipe Cactus National Monument	466
Shenandoah National Park - Thornton Gap Entrance	458
Guadalupe Mountains National Park	423
Shenandoah National Park - Front Royal Entrance	419

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

91 entered by BISC on 12/7 (Reported against EVER)

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

Theodore Roosevelt National Park - South Unit	416
Tonto National Monument	403
Padre Island National Seashore	387
Big South Fork National River & Recreation Area	377
Golden Spike National Historic Site	367
Lassen Volcanic National Park	363
Glen Canyon NRA	358
Shenandoah National Park - Rockfish Entrance	357
Shenandoah National Park - Swift Run Entrance	350
Capitol Reef National Park	343
Lava Beds National Monument	334
Carl Sandburg Home National Historic Site	317
Edison National Historical Park	316
Chaco Culture National Historical Park	287
Florissant Fossil Beds National Monument	277
National Historic Oregon Trail Interpretive Center	276
Saguaro National Park	264
Gila Cliff Dwellings National Monument	262
Haleakala National Park	251
White Sands National Monument	250
Cape Cod National Seashore - Salt Pond V.C.	231
Craters of the Moon National Monument	228
Bighorn Canyon National Recreation Area	219
Kings Mountain National Military Park	218
Cape Cod National Seashore - Provincelands V.C.	211
Hot Springs National Park	209
Chickamauga & Chattanooga National Military Park	203
Big Bend National Park	197
Obed Wild and Scenic River	192
Gulf Islands National Seashore	187
Mammoth Cave National Park	185
Fort Washington Park	184
Klondike Gold Rush National Historical Park	169
Scotts Bluff National Monument	166
Fossil Butte National Monument	164
Aztec Ruins National Monument	163
Bandalier National Monument	161
Timpanogos Cave National Monument	159
Sunset Crater Volcano National Monument	149
Weir Farm National Historic Site	143
Antietam National Battlefield	142
Whiskeytown National Recreation Area	139
William Howard Taft National Historical Site	135
Fort Smith National Historic Site	132
Canaveral National Seashore	129

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

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17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

Mount Rushmore National Memorial	128
Denali National Park & Preserve	120
Jewel Cave National Monument	120
Brown v Board of Education National Historic Site	119
Little Bighorn Battlefield National Monument	117
Prince William Forest Park	113
Alcatraz Island (see Golden Gate NRA)	103
Saint Gaudens National Historic Site	102
Greenbelt Park	98
Coronado National Monument	93
Virgin Islands National Park	90
Steamtown National Historic Site	88
Jefferson National Expansion Memorial	81
Gateway National Recreation Area - Sandy Hook	78
Pipestone National Monument	72
Rainbow Bridge National Monument (see Glen Canyon, UT)	61
Wilson's Creek National Battlefield	57
Lewis & Clark NHT/NPS Midwest Regional Office	53
Point Reyes National Seashore	50
Harry S Truman National Historic Site	49
Chickasaw National Recreation Area	48
Black Canyon of the Gunnison	47
Fort Davis National Historic Site	46
Great Basin National Park	46
Fort Moultrie National Monument	42
Lincoln Boyhood National Memorial	41
Wind Cave National Park	40
Fort Union National Monument	35
Tuzigoot National Monument	34
Wupatki National Monument	34
Great Smoky Mountain NP - Cades Cove Campground	31
Saratoga National Historical Park	30
Natural Bridges National Monument	30
Redwood National Park	27
Apostle Islands National Lakeshore	27
Vicksburg National Military Park	27
Mississippi National River & Recreation Area	24
Chickamauga and Chattanooga NMP- Lookout Mountain	22
Pipe Spring National Monument	18
Great Smoky Mountains NP - Sugarland VC	12
Theodore Roosevelt National Park - North Unit	12
Guilford Courthouse National Military Park	12
Isle Royale National Park	11
Great Smoky Mountains NP - Oconaluftee Visitor's Center	10
Biscayne National Park	10

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

91 entered by BISC on 12/7 (Reported against EVER)

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

Alaska Public Lands Visitor Center - Anchorage	7
Tuzigoot National Monument	6
Johnstown Flood National Memorial	6
Marsh-Billings-Rockefeller National Historical Park	5
Herbert Hoover National Historical Site	5
Fort Necessity National Battlefield	4
Great Smoky Mountains NP - Smokemont Campground	3
Valles Caldera National Preserve	3
San Antonio Missions National Historic Park	2
Homestead National Monument of America	2
Allegheny Portage Railroad National Historic Site	2
Glen Canyon NRA (both AZ and UT)	2
USACE	**10,607**
Mississippi River Project	2,284
Philpott Lake	1,349
Allatoona	969
Falls Lake	695
Wappapello Lake	477
Table Rock Lake	416
Proctor lake	396
Lake Shelbyville	365
Gull Lake Recreation Area	360
Englebright Lake	318
Raystown Lake Project	246
Willamette Valley Project (Cottage Grove/Dorena)	240
Sam Rayburn Lake	235
Crosslake Recreation Area	215
Jordan Lake	195
Sandy Lake Recreation Area	191
Carters	176
Cochiti Lake	159
Greers Ferry Lake	153
Woodruff-Seminole	150
Lanier	149
W. Kerr Scott Dam and Reservoir	144
Success Lake	124
Bonneville Lock and Dam- Bradford Island Visitor Center	115
John H. Kerr Dam and Reservoir	112
Cordell Hull Lake	75
Thurmond Project	50
Eastman Lake	50
Black Butte Lake	49
Cottage Grove Lake - Pine Meadows Campground	38
Leech Lake Recreation Area	27

5.3%

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

Gillham Lake	23
Mark Twain Lake	14
Taylorsville Lake	6
West Hill Dam	6
Buffumville Lake	5
Coralville Lake	3
The Dalles Lock and Dam- Visitor Center	3
Beaver Lake	2
North Hartland Lake	2
J. Percy Priest Lake	2
Keystone Lake	2
Clinton Lake Project	2
Smithville Lake Project	2
Eau Galle Recreation Area	2
Pine Creek	1
Hensley Lake	1
Shenango River Lake	1
Georgetown Lake	1
Hop Brook Lake	1
Abiquiu Lake	1
Canton Lake	1
Cowanesque Lake Project	1
Tioga-Hammond Lakes Project	1
Bay Model Visitor Center	1
Barren River Lake	1

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014015;17-01174_014015;17-01174_014016;17-01174_014017;17-01174_014018;17-01174_014019;1...

17-01174_014063;17-01174_014063;17-01174_014064

To: [redacted] (b)(6)-White House Staff [redacted] (b)(6)-White House Staff
From: Goklany, Indur
Sent: 2017-09-05T08:37:05-04:00
Importance: Normal
Subject: Fwd: Contacts
Received: 2017-09-05T08:37:32-04:00

Hello Christopher,
Ryan NIcholls, who is now at DOI, tells me that you are CEQ working on natural resources issues. I have been working on climate change for the Department for the Deputy Secretary's office, and would like to meet with you at your earliest convenience. I could meet with any day this week. Could you give me a time that would be convenient for you. I can come down to the CEQ offices.
Thanks.

Regards,

Indur Goklany
Sr. Advisor, Office of Policy Analysis

---------- Forwarded message ----------
From: **Nichols, Ryan** <ryan_nichols@ios.doi.gov>
Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni
Associate Director for Natural Resources
Council on Environmental Quality
[redacted] (b)(6)-White House Staff
(202) 395-5750
Executive Office of the President
730 Jackson Place, NW
Washington, DC 20503

J. Michael Kuperberg, Ph.D.
Executive Director
U.S. Global Change Research Program
mkuperberg@usgcrp.gov
(202) 419-3485
1800 G St NW, Suite 9100
Washington, DC 20006
www.globalchange.gov

--
Ryan Nichols

17-01174_014063;17-01174_014063;17-01174_014064

Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

17-01174_014065;17-01174_014065;17-01174_014066

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Prandoni, Christopher D. EOP/CEQ
Sent: 2017-09-05T11:33:19-04:00
Importance: Normal
Subject: RE: Contacts
Received: 2017-09-05T11:33:27-04:00

Hey Indur, thank you for reaching out. Is 2:30pm on Friday work for you? If not I can move some things around.

Chris

From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
Sent: Tuesday, September 5, 2017 8:37 AM
To: Prandoni, Christopher D. EOP/CEQ <[redacted]>
Subject: Fwd: Contacts

Hello Christopher,

Ryan NIcholls, who is now at DOI, tells me that you are CEQ working on natural resources issues. I have been working on climate change for the Department for the Deputy Secretary's office, and would like to meet with you at your earliest convenience. I could meet with any day this week. Could you give me a time that would be convenient for you. I can come down to the CEQ offices.
Thanks.

Regards,

Indur Goklany
Sr. Advisor, Office of Policy Analysis

---------- Forwarded message ----------
From: **Nichols, Ryan** <ryan_nichols@ios.doi.gov>
Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni
Associate Director for Natural Resources
Council on Environmental Quality
[redacted]
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730 Jackson Place, NW
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J. Michael Kuperberg, Ph.D.
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mkuperberg@usgcrp.gov
(202) 419-3485
1800 G St NW, Suite 9100
Washington, DC 20006
>www.globalchange.gov<

--

Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

To: Prandoni, Christopher D. EOP/CEQ[[redacted]]
From: Goklany, Indur
Sent: 2017-09-05T11:37:40-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-05T11:38:07-04:00

Thanks for getting back to me. 2:30 on Friday works for me. I'll send you an invite so that it gets on our calendars. See you then.
Goks (AKA Indur Goklany)

On Tue, Sep 5, 2017 at 11:33 AM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

Hey Indur, thank you for reaching out. Is 2:30pm on Friday work for you? If not I can move some things around.

Chris

From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
Sent: Tuesday, September 5, 2017 8:37 AM
To: Prandoni, Christopher D. EOP/CEQ <[redacted]>
Subject: Fwd: Contacts

Hello Christopher,

Ryan NIcholls, who is now at DOI, tells me that you are CEQ working on natural resources issues. I have been working on climate change for the Department for the Deputy Secretary's office, and would like to meet with you at your earliest convenience. I could meet with any day this week. Could you give me a time that would be convenient for you. I can come down to the CEQ offices.

Thanks.

Regards,

Indur Goklany

Sr. Advisor, Office of Policy Analysis

---------- Forwarded message ----------
From: **Nichols, Ryan** <ryan_nichols@ios.doi.gov>
Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

[redacted] (b)(6)-White House Staff

(202) 395-5750

Executive Office of the President

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Washington, DC 20503

J. Michael Kuperberg, Ph.D.

Executive Director

U.S. Global Change Research Program

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1800 G St NW, Suite 9100

Washington, DC 20006

>www.globalchange.gov<

--

Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

17-01174_014070;17-01174_014070

To: Goklany, Indur[indur_goklany@ios.doi.gov]
Cc: Ryan Nichols[ryan_nichols@ios.doi.gov]; Palumbo, David[dpalumbo@usbr.gov]; Virginia Burkett[virginia_burkett@usgs.gov]; William Werkheiser[whwerkhe@usgs.gov]
From: Raff, David
Sent: 2017-09-07T16:42:58-04:00
Importance: Normal
Subject: Uncertainty Language
Received: 2017-09-07T16:43:13-04:00
Uncertainty_09072017_forDept.docx

Good Afternoon Goks,
Per our discussion last week please find attached proposed uncertainty language to be used in future Reclamation planning studies. We have incorporated comments and edits internally here at Reclamation as well as with USGS. Please let us know if you have an additional insights or concerns. To reiterate there would still be additional uncertainty discussions within each technical chapter and report but that this would be proposed to be upfront in planning documents with minor alterations to fit each specific project.

Finally as we discussed would like to keep under two pages to match expectations of a summary or executive summary for planning studies and are hoping you will have the opportunity to review in the next couple weeks.

We still owe you both the final Klamath Basin Study and the Niobrara when it goes to OMB. I will get you those shortly.

Thank you,
Dave
--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 |
draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

Uncertainty

The information presented in this report was developed in collaboration with basin stakeholders and was peer reviewed in accordance with the Bureau of Reclamation and Department of the Interior polices. This report is intended to inform and support planning for the future by identifying potential future scenarios. The analyses provided in this report reflect the use of best available datasets and methodologies at the time of the study.

Water resources studies are developed in collaboration with basin stakeholders to evaluate potential future scenarios to assess risks and potential actions that can be taken to minimize impacts, including supply and demand imbalances. These types of studies support a proactive approach to water resources management, using the best available science and information to develop scenarios of future conditions within the watershed. This positions communities to take steps now to mitigate the impacts of future water supply management issues, including water shortages, impacts of droughts and floods, variations in water supply, and changing water demands for water for new or different uses.

Because every water resources planning study requires the study partners to make assumptions about future conditions, addressing the uncertainties in those assumptions is an essential component of the planning process. For example, there are uncertainties associated with the characterization of future water supply and demand, demographics, environmental and other policies, economic projections, climate conditions, and land use, to name a few. Moreover, projections are often developed using modeling techniques that themselves are only potential representations of a particular process or variable, and therefore, introduce additional uncertainties into characterizations of the future. Recognizing these uncertainties, and making adjustments to account for them, allows Reclamation and its stakeholders to use the best available science to create a range of possible future risks that can be used to identify appropriate adaptation strategies, which is fundamental to the planning process. Importantly, scenarios of future conditions should not be interpreted as a prediction of the future, nor is the goal of any water resources planning study to focus on a singular future. Rather the goal is to plan for a range of possible conditions and, thus, provide decision support tools for water managers.

Of significant interest are projections of future climate, which ultimately drive many assumptions of water supplies and demands through their influence on the water cycle. Projections of future climate are developed using the scientific communities' best assessment of potential future conditions as characterized by global climate models (GCMs). GCM projections are based upon initial model states, assumptions of future greenhouse gases in the atmosphere, and internal as well as external forcings, such as solar radiation and volcanic activity to name just a few. Changes in land surface, atmosphere, and ocean dynamics, as well as how such changes are best modeled in GCMs continue to be areas of active research. Depending on these and other uncertainties, projected future conditions, such as the magnitude of temperature and precipitation changes, may vary.

Further, it is important to recognize that these models perform better at global rather than regional or watershed level scales. GCM performance globally is an ongoing area of active research as differences in model outputs and observations are characterized[1] and how measurement errors, internal variability, and model forcings can be improved to enhance future performance[2]. Accordingly, techniques must be employed to localize or "downscale" GCM output for applications such as basin-specific water resources planning studies. These downscaled projections of climate are used as inputs to hydrologic models to produce projected streamflows, which are then used to assess impacts to the water resource system in

question. Uncertainties at each of the steps necessary to translate GCM output to water resources impacts can be characterized and adjusted for, yet uncertainties remain in the downscaling process that can result in variations depending on the modeling technique used.

Ultimately, future conditions at any particular time or place cannot be known exactly, given the current scientific understanding of potential future conditions. Likewise, it is important to recognize that the risks and impacts are the result of collective changes at a given location. Warming and increased carbon dioxide may increase plant water use efficiency, lengthen the agricultural growing season, but may also have adverse effects on snowpack and water availability. These complex interactions underscore the importance of using a planning approach that identifies future risks to water resources systems based on a range of plausible future conditions and working with stakeholders to evaluate options that minimize potential impacts in ways most suitable for all stakeholders involved.

1. IPCC Climate Change 2013: The Physical Science Basis (eds Stocker, T.F. et al.) 29 (Cambridge Univ. Press, 2013)
2. Santer, B.D., Fyfe, J.C., Pallotta, G., Flato, G.M., Meehl, G.A., England, M.H., Hawkins, E., Mann, M.E., Painter, J.F., Bonfils, C., Evijanovic, I., Mears, C., Wentz, F.J., Po-Chedley, S., Fu, Q., Zou, C.: Causes of differences in model and satellite trophospheric warming rates, Nature Geosciences, June 2017, DOI: 10.1038/NGEO2973.

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Prandoni, Christopher D. EOP/CEQ
Sent: 2017-09-08T13:02:57-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-08T13:04:48-04:00

Can e met at 3? Sorry but getting pulled into something.

Sent from my iPhone

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From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
Sent: Tuesday, September 5, 2017 8:37 AM
To: Prandoni, Christopher D. EOP/CEQ [redacted]
Subject: Fwd: Contacts

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Indur Goklany

Sr. Advisor, Office of Policy Analysis

---------- Forwarded message ----------
From: **Nichols, Ryan** <ryan_nichols@ios.doi.gov>
Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

(b)(6)-White House Staff

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Executive Office of the President

730 Jackson Place, NW

Washington, DC 20503

J. Michael Kuperberg, Ph.D.

Executive Director

U.S. Global Change Research Program

mkuperberg@usgcrp.gov

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1800 G St NW, Suite 9100

Washington, DC 20006

>>www.globalchange.gov<<

--

Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

To: Prandoni, Christopher D. EOP/CEQ[[redacted]
From: Goklany, Indur
Sent: 2017-09-08T13:05:54-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-08T13:06:22-04:00

Sure. Are you at 722 Jackson Pl?

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Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

17-01174_014079;17-01174_014079;17-01174_014080;17-01174_014081

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Prandoni, Christopher D. EOP/CEQ
Sent: 2017-09-08T13:47:47-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-08T13:47:56-04:00

Close. 730 jp

Sent from my iPhone

On Sep 8, 2017, at 1:21 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

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--

Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

17-01174_014082;17-01174_014082;17-01174_014083;17-01174_014084

To: Prandoni, Christopher D. EOP/CEQ[[redacted]
From: Goklany, Indur
Sent: 2017-09-08T14:10:29-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-08T14:10:56-04:00

See you then.

On Fri, Sep 8, 2017 at 1:47 PM, Prandoni, Christopher D. EOP/CEQ
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From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]

17-01174_014082;17-01174_014082;17-01174_014083;17-01174_014084

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Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

To: Prandoni, Christopher D. EOP/CEQ[[redacted]]
From: Goklany, Indur
Sent: 2017-09-12T11:50:08-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-12T11:50:35-04:00

Hello Chris -- Any progress on setting up a mtg? I hope to come to the mtg with Andrea Travnicek, who is acting Assistant Secretary for Water & Science, to whom USGS and the Bureau of Reclamation report. -- Goks (202-208-4951)

On Fri, Sep 8, 2017 at 1:47 PM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

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17-01174_014085;17-01174_014085;17-01174_014086;17-01174_014087

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[redacted]

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--

Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

17-01174_014088;17-01174_014088;17-01174_014089;17-01174_014090

To: Raff, David[draff@usbr.gov]
Cc: Ryan Nichols[ryan_nichols@ios.doi.gov]; Palumbo, David[dpalumbo@usbr.gov]; Virginia Burkett[virginia_burkett@usgs.gov]; William Werkheiser[whwerkhe@usgs.gov]
From: Goklany, Indur
Sent: 2017-09-12T15:21:43-04:00
Importance: Normal
Subject: Re: Uncertainty Language
Received: 2017-09-12T15:22:14-04:00

My edits are on the attached.

Also, just for information, following is the abstract of a new paper that indicates that CO2 may have increased the water use efficiency of plants globally. Unfortunately, I don't have access to the full text version.

==

Atmospheric evidence for a global secular increase in carbon isotopic discrimination of land photosynthesis

Ralph F. Keeling[a,1],
Heather D. Graven[b,c],
Lisa R. Welp[d],
Laure Resplandy[a],
Jian Bi[a],
Stephen C. Piper[a],
Ying Sun[e],
Alane Bollenbacher[a], and
Harro A. J. Meijer[f]

Author Affiliations

Edited by Mark H. Thiemens, University of California, San Diego, La Jolla, CA, and approved August 10, 2017 (received for review November 23, 2016)

1. Abstract
2. Full Text
3. Authors & Info
4. Figures
5. SI
6. Metrics
7. Related Content
8. PDF
9. PDF + SI

Significance

Climate change and rising CO_2 are altering the behavior of land plants in ways that influence how much biomass they produce relative to how much water they need for growth. This study shows that it is possible to detect changes occurring in plants using long-term measurements of the isotopic composition of atmospheric CO_2. These measurements imply that plants have globally

17-01174_014088;17-01174_014088;17-01174_014089;17-01174_014090

increased their water use efficiency at the leaf level in proportion to the rise in atmospheric CO_2 over the past few decades. While the full implications remain to be explored, the results help to quantify the extent to which the biosphere has become less constrained by water stress globally.

Abstract

A decrease in the $^{13}C/^{12}C$ ratio of atmospheric CO_2 has been documented by direct observations since 1978 and from ice core measurements since the industrial revolution. This decrease, known as the ^{13}C-Suess effect, is driven primarily by the input of fossil fuel-derived CO_2 but is also sensitive to land and ocean carbon cycling and uptake. Using updated records, we show that no plausible combination of sources and sinks of CO_2 from fossil fuel, land, and oceans can explain the observed ^{13}C-Suess effect unless an increase has occurred in the $^{13}C/^{12}C$ isotopic discrimination of land photosynthesis. A trend toward greater discrimination under higher CO_2 levels is broadly consistent with tree ring studies over the past century, with field and chamber experiments, and with geological records of C_3 plants at times of altered atmospheric CO_2, but increasing discrimination has not previously been included in studies of long-term atmospheric $^{13}C/^{12}C$ measurements. We further show that the inferred discrimination increase of 0.014 ± 0.007‰ ppm^{-1} is largely explained by photorespiratory and mesophyll effects. This result implies that, at the global scale, land plants have regulated their stomatal conductance so as to allow the CO_2 partial pressure within stomatal cavities and their intrinsic water use efficiency to increase in nearly constant proportion to the rise in atmospheric CO_2concentration.

===

On Thu, Sep 7, 2017 at 4:42 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Goks,
Per our discussion last week please find attached proposed uncertainty language to be used in future Reclamation planning studies. We have incorporated comments and edits internally here at Reclamation as well as with USGS. Please let us know if you have an additional insights or concerns. [redacted] (b)(5)

(b)(5)

Finally as we discussed would like to keep under two pages to match expectations of a summary or executive summary for planning studies and are hoping you will have the opportunity to review in the next couple weeks.

We still owe you both the final Klamath Basin Study and the Niobrara when it goes to OMB. I will get you those shortly.

Thank you,
Dave
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David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

17-01174_014088;17-01174_014088;17-01174_014089;17-01174_014090

17-01174_014091;17-01174_014091;17-01174_014092;17-01174_014093

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Raff, David
Sent: 2017-09-12T15:27:58-04:00
Importance: Normal
Subject: Re: Uncertainty Language
Received: 2017-09-12T15:28:05-04:00

Hi Goks,
I don't see an attachment could you try to resend?

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

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17-01174_014094;17-01174_014094;17-01174_014095;17-01174_014096

To: Raff, David[draff@usbr.gov]
Cc: Ryan Nichols[ryan_nichols@ios.doi.gov]; Palumbo, David[dpalumbo@usbr.gov]; Virginia Burkett[virginia_burkett@usgs.gov]; William Werkheiser[whwerkhe@usgs.gov]
From: Goklany, Indur
Sent: 2017-09-12T15:31:41-04:00
Importance: Normal
Subject: Re: Uncertainty Language
Received: 2017-09-12T15:32:12-04:00
Uncertainty_09072017_forDept.ig.docx

Thanks David. Here is the attachment. Sorry for forgetting to include it -- got too interested in the abstract.

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Uncertainty

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The information presented in this report was developed in collaboration with basin stakeholders and was peer reviewed in accordance with the Bureau of Reclamation and Department of the Interior polices. This report is intended to inform and support planning for the future by identifying potential future scenarios. The analyses provided in this report reflect the use of best available datasets and methodologies at the time of the study.

Water resources studies are developed in collaboration with basin stakeholders to evaluate potential future scenarios to assess risks and potential actions that can be taken to minimize impacts, including supply and demand imbalances. These types of studies support a proactive approach to water resources management, using the best available science and information to develop scenarios of future conditions within the watershed. This positions communities to take steps now to mitigate the impacts of future water supply management issues, including water shortages, impacts of droughts and floods, variations in water supply, and changing water demands for water for new or different uses.

Because every water resources planning study requires the study partners to make assumptions about future conditions, addressing the uncertainties in those assumptions is an essential component of the planning process. For example, there are uncertainties associated with the characterization of future water supply and demand, demographics, environmental and other policies, economic projections, climate conditions, and land use, to name a few. Moreover, projections are often developed using modeling techniques that themselves are only potential representations of a particular process or variable, and therefore, introduce additional uncertainties into characterizations of the future. Because of the complexities involved, this study has not developed estimates of the range of cumulative uncertainties resulting from the various uncertainties acting on each other. Recognizing these uncertainties, and making adjustments to account for them where possible, nevertheless allows Reclamation and its stakeholders to use the best available science to create a range of possible future risks that can be used to help identify appropriate adaptation strategies, which is fundamental to the planning process. Importantly, scenarios of future conditions should not be interpreted as a prediction of the future, nor is the goal of any water resources planning study to focus on a singular future. Rather the goal is to plan for a range of possible conditions and, thus, provide decision support tools for water managers.

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Of significant interest are projections of future climate, which ultimately drive many assumptions of water supplies and demands through their influence on the water cycle.

Projections of future climate are developed using the scientific communities' best assessment of potential future conditions as characterized by global climate models (GCMs). GCM projections are based upon initial model states, assumptions of future greenhouse gases in the atmosphere, and internal as well as external forcings, such as solar radiation and volcanic activity to name just a few. Changes in land surface, atmosphere, and ocean dynamics, as well as how such changes are best modeled in GCMs continue to be areas of active research. Depending on these and other uncertainties, projected future conditions, such as the magnitude of temperature and precipitation changes, may vary. Recent comparisons of GCM model projections versus observations suggest that the projections may be overestimating the rate of global warming, for whatever reason.[1,2] The evaluation and refinement of GCM performance is an ongoing area of research and includes methods to characterize model outputs and observations, and how measurement errors, internal variability, and model forcings can be improved to enhance future performance[2,3].

Commented [GIM1]: This was moved, with minor editing, from the following paragraph, because it seems to flow better here.

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Further, it is important to recognize that these models perform better at global rather than regional or watershed level scales. Accordingly, techniques must be employed to localize or "downscale" GCM output for applications such as basin-specific water resources planning studies. These downscaled projections of climate are used as inputs to hydrologic models to produce projected streamflows, which are then used to assess impacts to the water resource system in question. Uncertainties at each of the steps necessary to translate GCM output to water resources impacts can be characterized and adjusted for, yet uncertainties remain in the downscaling process that can result in variations depending on the modeling technique used.

Ultimately, future conditions at any particular time or place cannot be known exactly, given the current scientific understanding of potential future conditions. Likewise, it is important to recognize that the risks and impacts are the result of collective changes at a given location. Warming and increased carbon dioxide may increase plant water use efficiency, lengthen the agricultural growing season, but may also have adverse effects on snowpack and water availability. These complex interactions underscore the importance of using a planning approach that identifies future risks to water resources systems based on a range of plausible future conditions and working with stakeholders to evaluate options that minimize potential impacts in ways most suitable for all stakeholders involved.

1. IPCC Climate Change 2013: The Physical Science Basis (eds Stocker, T.F. et al.) 29 (Cambridge Univ. Press, 2013)

2. Santer, B.D., Solomon, S., Pallotta, G., Mears, C., Po-Chedley, S., Fu, Q., Wentz, F., Zou, C.Z., Painter, J., Cvijanovic, I. and Bonfils, C., 2017. Comparing tropospheric warming in climate models and satellite data. *Journal of Climate*, *30*(1), pp.373-392.
3. Santer, B.D., Fyfe, J.C., Pallotta, G., Flato, G.M., Meehl, G.A., England, M.H., Hawkins, E., Mann, M.E., Painter, J.F., Bonfils, C., Evijanovic, I., Mears, C., Wentz, F.J., Po-Chedley, S., Fu, Q., Zou, C.: Causes of differences in model and satellite tropospheric warming rates, Nature Geosciences, June 2017, DOI: 10.1038/NGEO2973.

To: Prandoni, Christopher D. EOP/CEQ[Christopher.D.Prandoni@ceq.eop.gov]
From: Goklany, Indur
Sent: 2017-09-21T08:40:35-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-21T08:41:03-04:00

Any news? Thanks -- Goks (202-208-4951)

On Tue, Sep 12, 2017 at 11:50 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Hello Chris -- Any progress on setting up a mtg? I hope to come to the mtg with Andrea Travnicek, who is acting Assistant Secretary for Water & Science, to whom USGS and the Bureau of Reclamation report. -- Goks (202-208-4951)

On Fri, Sep 8, 2017 at 1:47 PM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

Close. 730 jp

Sent from my iPhone

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From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
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Subject: Fwd: Contacts

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Regards,

Indur Goklany

Sr. Advisor, Office of Policy Analysis

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Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

(b)(6)-White House Staff

(202) 395-5750

Executive Office of the President

730 Jackson Place, NW

Washington, DC 20503

J. Michael Kuperberg, Ph.D.

Executive Director

U.S. Global Change Research Program

mkuperberg@usgcrp.gov

(202) 419-3485

1800 G St NW, Suite 9100

Washington, DC 20006

>>>www.globalchange.gov<<<

--

Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

To: Goklany, Indur[indur_goklany@ios.doi.gov]
From: Prandoni, Christopher D. EOP/CEQ
Sent: 2017-09-21T08:55:57-04:00
Importance: Normal
Subject: RE: Contacts
Received: 2017-09-21T08:56:07-04:00

Yup. Will schedule something for early next week.

Chris Prandoni
Associate Director for Natural Resources
Council on Environmental Quality

From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
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[redacted]
(202) 395-5750
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730 Jackson Place, NW
Washington, DC 20503

J. Michael Kuperberg, Ph.D.
Executive Director
U.S. Global Change Research Program
mkuperberg@usgcrp.gov
(202) 419-3485

17-01174_014103;17-01174_014103;17-01174_014104;17-01174_014105

1800 G St NW, Suite 9100
Washington, DC 20006
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--
Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

17-01174_014106;17-01174_014106;17-01174_014107;17-01174_014108;17-01174_014109

To: Prandoni, Christopher D. EOP/CEQ[[redacted]]
Cc: Andrea Travnicek[andrea_travnicek@ios.doi.gov]
From: Goklany, Indur
Sent: 2017-09-21T08:58:04-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-21T08:58:31-04:00

Thanks. You'll need to coordinate with Andrea's calendar. I'm copying her on this.

On Thu, Sep 21, 2017 at 8:55 AM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

Yup. Will schedule something for early next week.

Chris Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

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Christopher Prandoni

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Council on Environmental Quality

[redacted] (b)(6)-White House Staff

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>>>>www.globalchange.gov<<<<

--

Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

To: Goklany, Indur[indur_goklany@ios.doi.gov]
Cc: Andrea Travnicek[andrea_travnicek@ios.doi.gov]
From: Prandoni, Christopher D. EOP/CEQ
Sent: 2017-09-21T09:38:02-04:00
Importance: Normal
Subject: RE: Contacts
Received: 2017-09-21T09:38:12-04:00

Thanks, Indur. Hello, Andrea!

Are you all available to swing by Jackson Place next Monday at 10am or Wednesday at 3:30?

Chris Prandoni
Associate Director for Natural Resources
Council on Environmental Quality

From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
Sent: Thursday, September 21, 2017 8:58 AM
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Cc: Andrea Travnicek <andrea_travnicek@ios.doi.gov>
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Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni
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Council on Environmental Quality
[redacted] (b)(6)-White House Staff
(202) 395-5750
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J. Michael Kuperberg, Ph.D.
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mkuperberg@usgcrp.gov
(202) 419-3485
1800 G St NW, Suite 9100
Washington, DC 20006
>>>>>www.globalchange.gov<<<<<

--
Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

To: Prandoni, Christopher D. EOP/CEQ[[redacted]]
Cc: Goklany, Indur[indur_goklany@ios.doi.gov]; Brown Michelle[michelle_brown@ios.doi.gov]
From: Andrea Travnicek
Sent: 2017-09-21T09:40:23-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-21T09:40:25-04:00

Hi Chris-
I am adding Michelle on to see what my schedule looks like next week. I am traveling some so I know my schedule is tight. I may have more time the week after but I will let her coordinate.

I look forward to working with you!
Andrea

Sent from my iPhone

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> Associate Director for Natural Resources
> Council on Environmental Quality
>
> **From:** Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
> **Sent:** Thursday, September 21, 2017 8:58 AM
> **To:** Prandoni, Christopher D. EOP/CEQ <[redacted]
> **Cc:** Andrea Travnicek <andrea_travnicek@ios.doi.gov>
> **Subject:** Re: Contacts
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--
Ryan Nichols
Advisor

Office of Assistant Secretary - Water & Science
Department of the Interior

Cc: Prandoni, Christopher D. EOP/CEQ[redacted]; Goklany, Indur[indur_goklany@ios.doi.gov]
From: Brown, Michelle
Sent: 2017-09-21T09:45:40-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-21T09:46:27-04:00

Good morning,

The suggested times of 10 and 3 are both very bad times for Andrea.

Any possibility of 12:30 or 2:15??

Michelle R. Brown
Office of the Assistant Secretary,
Water & Science
Department of the Interior
202-208-7187

On Thu, Sep 21, 2017 at 9:40 AM, Andrea Travnicek <andrea_travnicek@ios.doi.gov> wrote:

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On Sep 5, 2017, at 11:38 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Thanks for getting back to me. 2:30 on Friday works for me. I'll send you an invite so that it gets on our calendars. See you then.

Goks (AKA Indur Goklany)

On Tue, Sep 5, 2017 at 11:33 AM, Prandoni, Christopher D. EOP/CEQ [redacted] wrote:

Hey Indur, thank you for reaching out. Is 2:30pm on Friday work for you? If not I can move some things around.

Chris

From: Goklany, Indur
[mailto:indur_goklany@ios.doi.gov]
Sent: Tuesday, September 5, 2017 8:37 AM
To: Prandoni, Christopher D. EOP/CEQ [redacted] (b)(6)-White House Staff
Subject: Fwd: Contacts

Hello Christopher,

Ryan NIcholls, who is now at DOI, tells me that you are CEQ working on natural resources issues. I have been working on climate change for the Department for the Deputy Secretary's office, and would like to meet with you at your earliest convenience. I could meet with any day this week. Could you give me a time that would be convenient for you. I can come down to the CEQ offices.

Thanks.

Regards,

Indur Goklany

Sr. Advisor, Office of Policy Analysis

---------- Forwarded message ----------
From: **Nichols, Ryan** <ryan_nichols@ios.doi.gov>
Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

[redacted]

(202) 395-5750

Executive Office of the President

730 Jackson Place, NW

Washington, DC 20503

J. Michael Kuperberg, Ph.D.

Executive Director

U.S. Global Change Research Program

mkuperberg@usgcrp.gov

(202) 419-3485

1800 G St NW, Suite 9100

Washington, DC 20006

>>>>>www.globalchange.gov<<<<<

--

Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

17-01174_014117;17-01174_014117;17-01174_014118;17-01174_014119;17-01174_014120;17-01174_014121;1...

To: Brown, Michelle[michelle_brown@ios.doi.gov]
Cc: Prandoni, Christopher D. EOP/CEQ[[redacted]]
From: Goklany, Indur
Sent: 2017-09-21T10:10:31-04:00
Importance: Normal
Subject: Re: Contacts
Received: 2017-09-21T10:11:49-04:00

I'm open for those times on both Mon & Wed.

On Thu, Sep 21, 2017 at 9:45 AM, Brown, Michelle <michelle_brown@ios.doi.gov> wrote:

Good morning,

The suggested times of 10 and 3 are both very bad times for Andrea.

Any possibility of 12:30 or 2:15??

Michelle R. Brown
Office of the Assistant Secretary,
Water & Science
Department of the Interior
202-208-7187

On Thu, Sep 21, 2017 at 9:40 AM, Andrea Travnicek <andrea_travnicek@ios.doi.gov> wrote:

Hi Chris-
I am adding Michelle on to see what my schedule looks like next week. I am traveling some so I know my schedule is tight. I may have more time the week after but I will let her coordinate.

I look forward to working with you!
Andrea

Sent from my iPhone

On Sep 21, 2017, at 6:38 AM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

Thanks, Indur. Hello, Andrea!

Are you all available to swing by Jackson Place next Monday at 10am or Wednesday at 3:30?

Chris Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
Sent: Thursday, September 21, 2017 8:58 AM

To: Prandoni, Christopher D. EOP/CEQ <[redacted]>
Cc: Andrea Travnicek <andrea_travnicek@ios.doi.gov>
Subject: Re: Contacts

Thanks. You'll need to coordinate with Andrea's calendar. I'm copying her on this.

On Thu, Sep 21, 2017 at 8:55 AM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

Yup. Will schedule something for early next week.

Chris Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

From: Goklany, Indur [mailto:indur_goklany@ios.doi.gov]
Sent: Thursday, September 21, 2017 8:41 AM
To: Prandoni, Christopher D. EOP/CEQ <[redacted]>
Subject: Re: Contacts

Any news? Thanks -- Goks (202-208-4951)

On Tue, Sep 12, 2017 at 11:50 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Hello Chris -- Any progress on setting up a mtg? I hope to come to the mtg with Andrea Travnicek, who is acting Assistant Secretary for Water & Science, to whom USGS and the Bureau of Reclamation report. -- Goks (202-208-4951)

On Fri, Sep 8, 2017 at 1:47 PM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

Close. 730 jp

Sent from my iPhone

On Sep 8, 2017, at 1:21 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Sure. Are you at 722 Jackson Pl?

On Fri, Sep 8, 2017 at 1:02 PM, Prandoni, Christopher D. EOP/CEQ <[redacted]> wrote:

Can e met at 3? Sorry but getting pulled into something.

Sent from my iPhone

On Sep 5, 2017, at 11:38 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

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Goks (AKA Indur Goklany)

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Hey Indur, thank you for reaching out. Is 2:30pm on Friday work for you? If not I can move some things

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From: Goklany, Indur
[mailto:indur_goklany@ios.doi.gov]
Sent: Tuesday, September 5, 2017 8:37 AM
To: Prandoni, Christopher D. EOP/CEQ <[redacted]>
Subject: Fwd: Contacts

Hello Christopher,

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Thanks.

Regards,

Indur Goklany

Sr. Advisor, Office of Policy Analysis

---------- Forwarded message ----------
From: **Nichols, Ryan** <ryan_nichols@ios.doi.gov>
Date: Wed, Aug 30, 2017 at 3:02 PM
Subject: Contacts
To: Indur Goklany <indur_goklany@ios.doi.gov>

Christopher Prandoni

Associate Director for Natural Resources

Council on Environmental Quality

[redacted]

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Ryan Nichols

Advisor

Office of Assistant Secretary - Water & Science

Department of the Interior

17-01174_014123;17-01174_014123;17-01174_014124;17-01174_014125;17-01174_014126;17-01174_014127;1...

To: indur_goklany@ios.doi.gov[indur_goklany@ios.doi.gov]
Cc: virginia_burkett@usgs.gov[virginia_burkett@usgs.gov]; whwerkhe@usgs.gov[whwerkhe@usgs.gov]; Dan DuBray[DDuBray@usbr.gov]; ryan_nichols@ios.doi.gov[ryan_nichols@ios.doi.gov]; dpalumbo@usbr.gov[dpalumbo@usbr.gov]
From: David Raff
Sent: 2017-09-27T16:38:10-04:00
Importance: Normal
Subject: Uncertainty Language
Received: 2017-09-27T16:38:22-04:00
ATT00001.txt
Uncertainty_092517 (1).docx

Good Afternoon Goks,

Sorry for the delayed response. We appreciate the input on our previous draft language and support getting to some language on uncertainty that works for us all.

Although your edits were minor in magnitude it did take Reclamation and the USGS a little bit to incorporate those thoughts in a manner we are all comfortable with. We hope that this attached version hits on all these points. Please let us know if it meets your expectations.

Thank you,
Dave

17-01174_014133;17-01174_014133

Uncertainty

The information presented in this report was developed in collaboration with basin stakeholders and was peer reviewed in accordance with the Bureau of Reclamation and Department of the Interior polices. This report is intended to inform and support planning for the future by identifying potential future scenarios. The analyses provided in this report reflect the use of best available datasets and methodologies at the time of the study.

Water resources studies are developed in collaboration with basin stakeholders to evaluate potential future scenarios to assess risks and potential actions that can be taken to minimize impacts, including supply and demand imbalances. These types of studies support a proactive approach to water resources management, using the best available science and information to develop scenarios of future conditions within the watershed. This positions communities to take steps now to mitigate the impacts of future water supply management issues, including water shortages, impacts of droughts and floods, variations in water supply, and changing water demands for water for new or different uses.

Because every water resources planning study requires the study partners to make assumptions about future conditions, addressing the uncertainties in those assumptions is an essential component of the planning process. For example, there are uncertainties associated with the characterization of future water supply and demand, demographics, environmental and other policies, economic projections, climate conditions, and land use, to name a few. Moreover, projections are often developed using modeling techniques that themselves are only potential representations of a particular process or variable, and therefore, introduce additional uncertainties into characterizations of the future. The cumulative, interacting uncertainties are not well known in the scientific community and, therefore, are not presented within this study. By recognizing this at each process step, uncertainties are adjusted for and reduced when possible, to allow Reclamation and its stakeholders to use the best available science to create a range of possible future risks that can be used to help identify appropriate adaptation strategies, which is fundamental to the planning process. Importantly, scenarios of future conditions should not be interpreted as a prediction of the future, nor is the goal of any water resources planning study to focus on a singular future. Rather the goal is to plan for a range of possible conditions, thereby providing decision support tools for water managers.

Of significant interest are projections of future climate, which ultimately drive many assumptions of water supplies and demands through their influence on the water cycle. Projections of future climate are developed using the scientific communities' best assessment of potential future conditions as characterized by global climate models (GCMs). GCM projections are based upon initial model states, assumptions of future greenhouse gases in the atmosphere, and internal as well as external forcings, such as

solar radiation and volcanic activity to name just a few. Changes in land surface, atmosphere, and ocean dynamics, as well as how such changes are best modeled in GCMs continue to be areas of active research. Depending on these and other uncertainties, projected future conditions, such as the magnitude of temperature and precipitation changes, may vary. Observed climatic data and GCM simulations show warming trends over recent decades. However, the degree to which the magnitude of GCM simulated warming agrees with historic observations, where some studies find more GCM warming[1] while others show warming rates more in line with observations,[2, 3] varies based on the data, methods, and time periods used for making such comparisons. The evaluation and refinement of GCM performance is an ongoing area of research and includes methods to characterize model outputs and observations, and how measurement errors, internal variability, and model forcings can be improved to enhance future performance.[2]

Further, it is important to recognize that these models perform better at global rather than regional or watershed level scales. Accordingly, techniques must be employed to localize or “downscale” GCM output for applications such as basin-specific water resources planning studies. These downscaled projections of climate are used as inputs to hydrologic models to produce projected streamflows, which are then used to assess impacts to the water resource system in question. Uncertainties at each of the steps necessary to translate GCM output to water resources impacts can be characterized and adjusted for, yet uncertainties remain in the downscaling process that can result in variations depending on the modeling technique used.

Ultimately, future conditions at any particular time or place cannot be known exactly, given the current scientific understanding of potential future conditions. Likewise, it is important to recognize that the risks and impacts are the result of collective changes at a given location. Warming and increased carbon dioxide may increase plant water use efficiency, lengthen the agricultural growing season, but may also have adverse effects on snowpack and water availability. These complex interactions underscore the importance of using a planning approach that identifies future risks to water resources systems based on a range of plausible future conditions, and working with stakeholders to evaluate options that minimize potential impacts in ways most suitable for all stakeholders involved.

1. Santer, B.D., Solomon, S., Pallotta, G., Mears, C., Po-Chedley, S., Fu, Q., Wentz, F., Zou, C.Z., Painter, J., Cvijanovic, I. and Bonfils, C., 2017. Comparing tropospheric warming in climate models and satellite data. Journal of Climate, 30(1), pp.373-392.
2. Lin M, Huybers P, Lin M, Huybers P (2016) Revisiting Whether Recent Surface

Temperature Trends Agree with the CMIP5 Ensemble. Journal of Climate, 29, 8673–8687.

3. Richardson M, Cowtan K, Hawkins E, Stolpe MB (2016) Reconciled climate response estimates from climate models and the energy budget of Earth. Nature Climate Change, 6, 931–935.
4. Santer, B.D., Fyfe, J.C., Pallotta, G., Flato, G.M., Meehl, G.A., England, M.H., Hawkins, E., Mann, M.E., Painter, J.F., Bonfils, C., Evijanovic, I., Mears, C., Wentz, F.J., Po-Chedley, S., Fu, Q., Zou, C.: Causes of differences in model and satellite tropospheric warming rates, Nature Geosciences, June 2017, DOI: 10.1038/NGEO2973.

17-01174_014134;17-01174_014134;17-01174_014135;17-01174_014136

To: Indur Goklany[indur_goklany@ios.doi.gov]
From: Nichols, Ryan
Sent: 2017-10-04T16:01:40-04:00
Importance: Normal
Subject: Fwd: USGS study: Future Temperature & Soil Moisture Conditions May Alter Location of Ag Regions
Received: 2017-10-04T16:02:29-04:00
Bradford.DrylandAg.V8.docx
USGS Briefing Paper.Dryland Agriculture.9.29.2017.docx

Indur,
I thought you might be interested in this study on the effects of changing temperature/rainfall on agricultural productivity. This has not yet been published, so please don't share this.

---------- Forwarded message ----------
From: **Wade, Anne-Berry** <abwade@usgs.gov>
Date: Mon, Oct 2, 2017 at 11:08 AM
Subject: USGS policy review: Future Temperature and Soil Moisture Conditions May Alter Location of Agricultural Regions

Attached/pasted below is a press release announcing that future high temperature extremes and soil moisture conditions may cause some regions to become more suitable for rainfed, or non-irrigated, agriculture, while causing other areas to lose suitable farmland. The article is due to be published in *Scientific Reports* (a Nature publication) within the next week or two. A briefing paper written by the scientists is also attached for your information.

A.B. Wade
USGS Press Officer
703-648-4483 desk
703-317-7871 mobile

Communications Plan: Future Temperature and Soil Moisture Conditions May Alter Location of Agricultural Regions

- **National News Release:** Future high temperature extremes and soil moisture conditions may cause some regions to become more suitable for rainfed, or non-irrigated, agriculture, while causing other areas to lose suitable farmland.
- **Estimated Release Date:** early Oct.
- **Specific locations:** Flagstaff, Arizona
- **Background:** Future conditions will cause an overall increase in the area suitable to support rainfed agriculture within dryland areas. Increases are projected in North America, Western Asia, Eastern Asia and South America. In contrast, suitable areas are projected to decline in European dryland areas. This study focused on understanding and projecting suitability for rainfed agriculture in temperate, or non-tropical, dryland regions.
- **Partners/Stakeholders:**

- **Journal/Outlet:** Scientific Reports
- **Publication Status:** unpublished

- **Social Media Plans:** FB, Twitter, IG
- **Congressional Notification:** Likely
- **POC:** Jennifer LaVista

Future Temperature and Soil Moisture May Alter Location of Agricultural Regions

Future high temperature extremes and soil moisture conditions may cause some regions to become more suitable for rainfed, or non-irrigated, agriculture, while causing other areas to lose suitable farmland, according to a new U.S. Geological Survey study.

These future conditions will cause an overall increase in the area suitable to support rainfed agriculture within dryland areas. Increases are projected in North America, western Asia, eastern Asia and South America. In contrast, suitable areas are projected to decline in European dryland areas.

This study focused on understanding and projecting suitability for rainfed agriculture in temperate, or non-tropical, dryland regions. Drylands make up at least 40 percent of the earth's land area and rainfed croplands account for approximately 75 percent of global cropland. Worldwide, temperate regions account for 31 percent of the area used to grow wheat and 17 percent used for corn.

"Understanding the future potential distribution of rainfed agriculture is important for resource managers in meeting economic and food security needs, especially as the earth's population grows," said USGS scientist and lead author of the study, John Bradford.

Future climate conditions are expected to increase the frequency of high temperature events and alter the seasonality of soil moisture in dryland systems, which are the factors found to be important in predicting regions suitable for agriculture in these water-limited areas. Findings for the temperate regions examined by this study indicate that many areas currently too cold for agriculture, particularly across Asia and North America, will likely become suitable for growing crops. However, some areas that are currently heavily cultivated, including regions of the United States such as the southern Great Plains, are likely to become less suitable for agriculture in the future.

USGS scientists and an international team of collaborators from Switzerland, Germany, China, Canada and several U.S. universities found that rainfed agriculture is abundant in areas with adequate soil moisture but restricted in areas with regular high temperature extremes. Bradford and collaborators simulated future soil moisture and temperature conditions, and utilized these results to identify where rainfed agriculture may be located in the future.

"Our results indicate the interaction of soil moisture and temperature extremes provides a powerful yet simple framework for understanding the conditions that define suitability for rainfed agriculture in drylands," said Bradford. "Integrating this framework with long-term projections that include rising temperature and changing soil moisture patterns reveals potentially important future shifts in areas that could support agriculture in the absence of irrigation."

Within the dryland regions that were the focus of this study, areas suitable for agriculture are those that experience relatively long periods of moist soils and reasonably warm temperatures. In contrast, areas that frequently experience extreme air temperatures above 93 degrees Fahrenheit are less suitable for rainfed agriculture, even if sufficient moisture is available. Even for relatively cool dryland areas, periods of high temperatures during the growing season can negatively affect agriculture suitability.

USGS provides science for a changing world. Visit USGS.gov, and follow us on Twitter @USGS and our other social media channels.

###

--
Ryan Nichols
Advisor
Office of Assistant Secretary - Water & Science
Department of the Interior

science for a changing world

News Release

Oct XX, 2017	Jennifer LaVista	720-480-7875	jlavista@usgs.gov
	Todd Wojtowicz	928-556-7390	twojtowicz@usgs.gov
	John Bradford	928-523-7766	jbradford@usgs.gov

Future Temperature and Soil Moisture May Alter Location of Agricultural Regions

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Within the dryland regions that were the focus of this study, areas suitable for agriculture are those that experience relatively long periods of moist soils and reasonably warm temperatures. In contrast, areas that frequently experience extreme air temperatures above 93 degrees Fahrenheit are less suitable for rainfed agriculture, even if sufficient moisture is available. Even for relatively cool dryland areas, periods of high temperatures during the growing season can negatively affect agriculture suitability.

###

INFORMATION/BRIEFING MEMORANDUM

DATE: September 28, 2017
FROM: William H. Werkheiser, Acting Director, U.S. Geological Survey
SUBJECT: Paper to be published about potential future shifts in the distribution of areas suitable to support rainfed agriculture in temperate drylands

This purpose of this briefing memorandum is to inform the Acting Assistant Secretary for Water and Science (ASWS) about the findings of a U.S. Geological Survey (USGS) study that will be published in the online journal, *Scientific Reports*. The study, "Future soil moisture and temperature extremes imply expanding suitability for rainfed agriculture in temperate drylands" is expected to be published mid- to late October. The USGS Office of Communications will be coordinating with the Department (ASWS and DOI Communications) to issue a press release.

KEY TAKEAWAYS

- This research found that temperature extremes and soil moisture conditions provide a simple, yet powerful framework to predict areas that are suitable to support rainfed (non-irrigated) agriculture in dryland climates. Specifically, areas that support rainfed agriculture have prolonged periods of moist soils and reasonably warm temperatures. However, areas that frequently experience air temperatures above 93 °F (34 °C) are less suitable for rainfed agriculture, even if sufficient moisture is available.

- Within dryland regions of the temperate zone, increasing future temperatures and changing soil moisture conditions throughout the 21st century are predicted to cause an overall increase in the area suitable to support rainfed agriculture. Increases are expected primarily in parts of North America and Asia where current cold conditions restrict agricultural suitability.

- In contrast, other areas, notably European drylands, much of the southern Great Plains in the United States, and part of China, are predicted to become less suitable for rainfed agriculture in the future.

BACKGROUND

Drylands make up at least 40 percent of the Earth's land area and rainfed (non-irrigated) croplands account for approximately 75 percent of global cropland. Worldwide, dryland crop regions account for 31 percent of the area used to grow wheat and 17 percent used for corn. USGS scientists and an international team of collaborators from Switzerland, Germany, China, Canada, and several U.S. universities, characterized the controls over suitability for rainfed agriculture in temperate drylands, and assessed how changes in those controls driven by changes in climate may shift the distribution of areas suitable to support rainfed agriculture.

DISCUSSION

Other studies have indicated that historical trends in climate extremes over the past few decades have adversely impacted agricultural production, although those impacts are masked by advances

in agronomic technology, such as genetic crop improvements. However, crop improvements in the past several decades have increased rainfed crop yields and may be associated with greater drought vulnerability.

This study adds to that knowledge by identifying two important environmental influences over rainfed agriculture in temperate dryland areas. First, the number of days with extreme heat exerts important control over suitability for rainfed agriculture; this control may not be well represented by studies focusing only on mean climatic conditions or using a monthly time scale analysis. While extreme heat has a recognized impact on agricultural yields, its role in restricting the distribution of areas suitable for rainfed agriculture has not been previously demonstrated. Second, extreme heat interacts with the dominant control exerted by transient soil moisture availability in these dryland regions such that rainfed agriculture can be restricted by any combination of dry conditions or extreme heat. These interacting influences are especially important in the context of long-term directional climate change, because a growing potential for extreme heat events, more frequent ecological drought periods, and enhanced aridity in drylands are among the most reliable aspects of climate projections.

Our overall result of increasing suitability for rainfed agriculture is specific to drylands of the temperate zone. In the warmer conditions of tropical and subtropical regions, rainfed crop production is likely to be negatively impacted by rising temperatures; many of the regions identified by other studies as most at risk for declining crop yield due to climate change are in tropical and subtropical climates, and the portions of temperate drylands that we identified as declining in suitability for rainfed agriculture tend to occur at lower latitudes. Our result of extreme high temperatures negatively affecting rainfed agricultural suitability reinforces these previous findings and illustrates how the impact of changing climate on agriculture may differ between temperate regions and tropical/subtropical regions.

POSITION OF INTERESTED PARTIES

This study will be of interest to farmers and to natural resources decision makers (local, state, and Federal).

CONTACT: Dave Lytle, USGS, Director, Southwest Biological Science Center (dlytle@usgs.gov; 928-556-7194)

To: Raff, David[draff@usbr.gov]
Cc: Virginia Burkett[virginia_burkett@usgs.gov]; William Werkheiser[whwerkhe@usgs.gov]; Dan DuBray[DDuBray@usbr.gov]; Nichols, Ryan[ryan_nichols@ios.doi.gov]; Palumbo, David[dpalumbo@usbr.gov]
From: Goklany, Indur
Sent: 2017-10-05T16:07:30-04:00
Importance: Normal
Subject: Re: Uncertainty Language
Received: 2017-10-05T16:08:00-04:00
Uncertainty_092517.ig.docx

David -- Here are my comments. Call, if you want to discuss. Thanks -- Goks

On Wed, Oct 4, 2017 at 2:26 PM, Raff, David <draff@usbr.gov> wrote:

Thanks Goks.

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

On Wed, Oct 4, 2017 at 12:20 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Hello David,
It's on my to-do list. I hope to get something to you by COB tomorrow, if not sooner.
Thanks.

Goks

On Wed, Oct 4, 2017 at 11:00 AM, Raff, David <draff@usbr.gov> wrote:

Good Morning Goks,
Checking in to see if you have had the chance to go over this version and hoping that we are good to go.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

On Thu, Sep 28, 2017 at 5:55 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Thanks Dave. I'll take a look at it and get back to you.

Regards,
Goks

On Wed, Sep 27, 2017 at 4:38 PM, David Raff <draff@usbr.gov> wrote:

Good Afternoon Goks,

Sorry for the delayed response. We appreciate the input on our previous draft language and support getting to some language on uncertainty that works for us all.

Although your edits were minor in magnitude it did take Reclamation and the USGS a little bit to incorporate those thoughts in a manner we are all comfortable with. We hope that this attached version hits on all these points. Please let us know if it meets your expectations.

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Uncertainty

The information presented in this report was developed in collaboration with basin stakeholders and was peer reviewed in accordance with the Bureau of Reclamation and Department of the Interior polices. This report is intended to inform and support planning for the future by identifying potential future scenarios. The analyses provided in this report reflect the use of best available datasets and methodologies at the time of the study.

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Because every water resources planning study requires the study partners to make assumptions about future conditions, addressing the uncertainties in those assumptions is an essential component of the planning process. For example, there are uncertainties associated with the characterization of future water supply and demand, demographics, environmental and other policies, economic projections, climate conditions, and land use, to name a few. Moreover, projections are often developed using modeling techniques that themselves are only potential representations of a particular process or variable, and therefore, introduce additional uncertainties into characterizations of the future. The cumulative, interacting uncertainties are not yet well known in the scientific community and are not presented within this study. However, by recognizing this at each process step, uncertainties are adjusted for and reduced when possible, to allow Reclamation and its stakeholders to use the best available science to create a range of possible future risks that can be used to help identify appropriate adaptation strategies, which is fundamental to the planning process. Importantly, scenarios of future conditions should not be interpreted as a prediction of the future, nor is the goal of any water resources planning study to focus on a singular future. Rather the goal is to plan for a range of possible conditions, thereby providing decision support tools for water managers.

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Commented [GIM1]: I would recommend analyses of cumulative uncertainties in new and ongoing basin studies.

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solar radiation and volcanic activity to name just a few. Changes in land surface, atmosphere, and ocean dynamics, as well as how such changes are best modeled in GCMs continue to be areas of active research. Depending on these and other uncertainties, projected future conditions, such as the magnitude of temperature and precipitation changes, may vary.

Observed climatic data and GCM simulations show warming trends over recent decades. However, the degree to which the magnitude of GCM simulated warming agrees with historic observations[3] varies based on the data, methods, and time periods used for making such comparisons. Some recent studies have found that models have projected a higher rate of present day global warming relative to observations[1,2] ; another study showed that current warming is at the lower part of model projections[3]; and yet other studies — some using somewhat older or more limited set of model results — showed the observed and projected warming rates to be similar [4,5].The evaluation and refinement of GCM performance is an ongoing area of research and includes methods to characterize model outputs and observations, and how measurement errors, internal variability, and model forcings can be improved to enhance future performance.[2]

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Further, it is important to recognize that these models perform better at global rather than regional or watershed level scales. Accordingly, techniques must be employed to localize or “downscale” GCM output for applications such as basin-specific water resources planning studies. These downscaled projections of climate are used as inputs to hydrologic models to produce projected streamflows, which are then used to assess impacts to the water resource system in question. Uncertainties at each of the steps necessary to translate GCM output to water resources impacts can be characterized and adjusted for, yet uncertainties remain in the downscaling process that can result in variations depending on the modeling technique used.

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1. Santer, B.D., Solomon, S., Pallotta, G., Mears, C., Po-Chedley, S., Fu, Q., Wentz,

17-01174_014143;17-01174_014143;17-01174_014144;17-01174_014145

F., Zou, C.Z., Painter, J., Cvijanovic, I. and Bonfils, C., 2017. Comparing tropospheric warming in climate models and satellite data. Journal of Climate, 30(1), pp.373-392.

2. Santer, B.D., Fyfe, J.C., Pallotta, G., Flato, G.M., Meehl, G.A., England, M.H., Hawkins, E., Mann, M.E., Painter, J.F., Bonfils, C., Evijanovic, I., Mears, C., Wentz, F.J., Po-Chedley, S., Fu, Q., Zou, C.: Causes of differences in model and satellite tropospheric warming rates, Nature Geosciences, June 2017, DOI: 10.1038/NGEO2973.

3. Lin M, Huybers P (2016) Revisiting Whether Recent Surface Temperature Trends Agree with the CMIP5 Ensemble. Journal of Climate, 29, 8673–8687.
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Moved (insertion) [1]

Moved up [1]: ¶
Santer, B.D., Fyfe, J.C., Pallotta, G., Flato, G.M., Meehl, G.A., England, M.H., Hawkins, E., Mann, M.E., Painter, J.F., Bonfils, C., Evijanovic, I., Mears, C., Wentz, F.J., Po-Chedley, S., Fu, Q., Zou, C.: Causes of differences in model and satellite tropospheric warming rates, Nature Geosciences, June 2017, DOI: 10.1038/NGEO2973.

17-01174_014146;17-01174_014146;17-01174_014147;17-01174_014148

To: Goklany, Indur[indur_goklany@ios.doi.gov]
Cc: Virginia Burkett[virginia_burkett@usgs.gov]; William Werkheiser[whwerkhe@usgs.gov]; Dan DuBray[DDuBray@usbr.gov]; Nichols, Ryan[ryan_nichols@ios.doi.gov]; Palumbo, David[dpalumbo@usbr.gov]
From: Raff, David
Sent: 2017-10-06T12:31:41-04:00
Importance: Normal
Subject: Re: Uncertainty Language
Received: 2017-10-06T12:31:52-04:00
Uncertainty_092517.ig_dar.docx

Thanks again for your edits Goks,

We have made some further revisions to the additional language you provided. We have a couple primary concerns:

[redacted]

Thanks,

Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

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Uncertainty

The information presented in this report was developed in collaboration with basin stakeholders and was peer reviewed in accordance with the Bureau of Reclamation and Department of the Interior polices. This report is intended to inform and support planning for the future by identifying potential future scenarios. The analyses provided in this report reflect the use of best available datasets and methodologies at the time of the study.

Water resources studies are developed in collaboration with basin stakeholders to evaluate potential future scenarios to assess risks and potential actions that can be taken to minimize impacts, including supply and demand imbalances. These types of studies support a proactive approach to water resources management, using the best available science and information to develop scenarios of future conditions within the watershed. This positions communities to take steps now to mitigate the impacts of future water supply management issues, including water shortages, impacts of droughts and floods, variations in water supply, and changing water demands for water for new or different uses.

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To: Raff, David[draff@usbr.gov]
Cc: Virginia Burkett[virginia_burkett@usgs.gov]; William Werkheiser[whwerkhe@usgs.gov]; Dan DuBray[DDuBray@usbr.gov]; Nichols, Ryan[ryan_nichols@ios.doi.gov]; Palumbo, David[dpalumbo@usbr.gov]
From: Goklany, Indur
Sent: 2017-10-06T13:49:12-04:00
Importance: Normal
Subject: Re: Uncertainty Language
Received: 2017-10-06T13:49:38-04:00

Thanks David.
[redacted] (b)(5)

On Fri, Oct 6, 2017 at 12:31 PM, Raff, David <draff@usbr.gov> wrote:

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We have made some further revisions to the additional language you provided. We have a couple primary concerns:

[redacted] (b)(5)

[redacted]

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Dave

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David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

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17-01174_014155;17-01174_014155;17-01174_014156;17-01174_014157

To: Indur Goklany[indur_goklany@ios.doi.gov]
From: Apgar, Megan
Sent: 2017-10-24T13:05:26-04:00
Importance: Normal
Subject: Fwd: FOR EO 12866 REVIEW BY COB FRIDAY: EPA Advance Notice of Proposed Rulemaking (ANPRM): State Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units (RIN 2060-AT67)
Received: 2017-10-24T13:05:34-04:00
10102017 10 AM EGU GHG 111(D) ANPRM.DOCX

As discussed....

Thanks,
Megan Apgar
Executive Secretariat and Regulatory Affairs
Office of the Secretary
Department of the Interior
Voice: (202) 208-4582

---------- Forwarded message ----------
From: **Szabo, Aaron L. EOP/OMB** <[redacted]>
Date: Tue, Oct 10, 2017 at 1:08 PM
Subject: FOR EO 12866 REVIEW BY COB FRIDAY: EPA Advance Notice of Proposed Rulemaking (ANPRM): State Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units (RIN 2060-AT67)
To: "HHSExecSec@hhs.gov" <HHSExecSec@hhs.gov>, DOLRegPolicy <DOLRegPolicy@dol.gov>, WCTS - OBPA USDA Reg <usdareg@obpa.usda.gov>, "heidi.cohen@treasury.gov" <heidi.cohen@treasury.gov>, "amathew@doc.gov" <amathew@doc.gov>, "patricia.l.toppings.civ@mail.mil" <patricia.l.toppings.civ@mail.mil>, "nanette.jennings@nasa.gov" <nanette.jennings@nasa.gov>, "Brown, Kelly" <kBrown@doc.gov>, "Gc-71energyregs@hq.doe.gov" <Gc-71energyregs@hq.doe.gov>, "Daniel.Cohen@hq.doe.gov" <Daniel.Cohen@hq.doe.gov>, "elizabeth.kohl@hq.doe.gov" <elizabeth.kohl@hq.doe.gov>, "mark_lawyer@ios.doi.gov" <mark_lawyer@ios.doi.gov>, Megan Apgar <Megan_Apgar@ios.doi.gov>, "chip.smith1@us.army.mil" <chip.smith1@us.army.mil>, "ellen.brown@ferc.gov" <ellen.brown@ferc.gov>, "Rostker, David J." <David.Rostker@sba.gov>, "Waqar, Tayyaba" <tayyaba.waqar@sba.gov>, "Jones, Kevin R (OLP)" <Kevin.R.Jones@usdoj.gov>, "Hinchman, Robert (OLP) (Robert.Hinchman@usdoj.gov)" <Robert.Hinchman@usdoj.gov>, "Gormsen, Eric T (OLP) (Eric.T.Gormsen@usdoj.gov)" <Eric.T.Gormsen@usdoj.gov>, "DOT.Regulations@dot.gov" <DOT.Regulations@dot.gov>, "llo.resource@nrc.gov" <llo.resource@nrc.gov>, "Taylor, Bevin Wilkinson" <bewilkinson@tva.gov>, "Miller, Wendy (ENRD)" <Wendy.Miller@usdoj.gov>
Cc: "Szabo, Aaron L. EOP/OMB" <[redacted] "DeBruhl, Brandon F. EOP/OMB" <[redacted], "Laity, Jim A. EOP/OMB"
[redacted]

Interagency reviewers,

Please find attached for review under Executive Orders 12866, the U.S. Environmental Protection Agency's (EPA) draft Advance Notice of Proposed Rulemaking (ANPRM) entitled "State Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units" (RIN 2060-AT67).

Summary: An advance notice of proposed rulemaking (ANPRM) is a notice intended to solicit information from the public as the Environmental Protection Agency (EPA) considers whether it is appropriate to propose a rule. The EPA is assessing the scope of its legal authority to set emission guidelines to limit greenhouse gas (GHG) emissions from existing electric utility generating units (EGUs) and concurrently, how best to do so consistent with the Clean Air Act (CAA) and principles of cooperative federalism. This ANPRM solicits information on systems of emission reduction that are applicable within-the-fence-line of an EGU facility, information on compliance measures, and information on state-planning requirements under CAA section 111(d). This ANPRM does not propose any regulatory requirements.

Reminder: Under the governing EOs, these deliberative and pre-decisional documents are provided for review by federal executive branch agencies only and should not be distributed further. To note, Clean Air Act (CAA) Section 307(d)(4)(A) requires that all documents and comments between EPA and interagency reviewers be provided in the public docket. Therefore, all comments, verbal or written, should be done through OMB. I am happy to provide additional guidance if anyone has questions about the Executive Orders 12866 process and CAA docketing requirements.

Please provide me with any comments or questions on the attached draft ANPRM by **COB, Friday, October 13th, 2017**.

Aaron L. Szabo

Policy Analyst

Office of Information and Regulatory Affairs

Office of Management and Budget

202-395-3621

17-01174_014155;17-01174_014155;17-01174_014156;17-01174_014157

(b)(6)-White House Staff

6560-50-P

EO 12866_State GHG Guidelines 2060-AT67 ANPRM_20170921

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 60

[EPA–HQ–OAR–2017–0545; FRL–XXXX-XX-XXX]

RIN 2060-AT67

State Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units

AGENCY: Environmental Protection Agency (EPA).

ACTION: Advance notice of proposed rulemaking (ANPRM).

SUMMARY: An advance notice of proposed rulemaking (ANPRM) is a notice intended to solicit information from the public as the Environmental Protection Agency (EPA) considers whether it is appropriate to propose a rule. The EPA is assessing the scope of its legal authority to set emission guidelines to limit greenhouse gas (GHG) emissions from existing electric utility generating units (EGUs) and concurrently, how best to do so consistent with the Clean Air Act (CAA) and principles of cooperative federalism. This ANPRM solicits information on systems of emission reduction that are applicable within-the-fence-line of an EGU facility, information on compliance measures, and information on state-planning requirements under CAA section 111(d). This ANPRM does not propose any regulatory requirements.

DATES: Comments must be received on or before **[Insert date XX days after date of publication in the Federal Register]**.

ADDRESSES: *Comments*. Submit your comments, identified by Docket ID No. EPA-HQ-OAR-2017-0545, at *http://www.regulations.gov*. Follow the online instructions for submitting comments. Once submitted, comments cannot be edited or removed from Regulations.gov. The

EPA may publish any comment received to its public docket. Do not submit electronically any information you consider to be Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Multimedia submissions (audio, video, *etc.*) must be accompanied by a written comment. The written comment is considered the official comment and should include discussion of all points you wish to make. The EPA will generally not consider comments or comment contents located outside of the primary submission (*i.e.*, on the Web, cloud, or other file sharing system). For additional submission methods, the full EPA public comment policy, information about CBI or multimedia submissions, and general guidance on making effective comments, please visit *https://www.epa.gov/dockets/commenting-epa-dockets*.

Instructions. Direct your comments on the proposed rule to Docket ID No. EPA–HQ–OAR–2017–0545. The EPA's policy is that all comments received will be included in the public docket and may be made available online at *http://www.regulations.gov*, including any personal information provided, unless the comment includes information claimed to be CBI or other information whose disclosure is restricted by statute. Do not submit information that you consider to be CBI or otherwise protected through *http://www.regulations.gov* or email. The *http://www.regulations.gov* Web site is an "anonymous access" system, which means the EPA will not know your identity or contact information unless you provide it in the body of your comment. If you send an email comment directly to the EPA without going through *http://www.regulations.gov*, your email address will be automatically captured and included as part of the comment that is placed in the public docket and made available on the Internet. If you submit an electronic comment, the EPA recommends that you include your name and other contact information in the body of your comment and with any disk or CD–ROM you submit. If

the EPA cannot read your comment due to technical difficulties and cannot contact you for clarification, the EPA may not be able to consider your comment. Electronic files should avoid the use of special characters, any form of encryption, and be free of any defects or viruses.

Docket. The EPA has established a new docket for this action under Docket ID No. EPA–HQ–OAR–2017–0545. The EPA previously established a docket for the October 23, 2015, Clean Power Plan (CPP) under Docket ID No. EPA–HQ–OAR–2013–0602. All documents in the docket are listed in the *http://www.regulations.gov* index. Although listed in the index, some information is not publicly available, *e.g.*, CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, will be publicly available only in hard copy form. Publicly available docket materials are available either electronically at *http://www.regulations.gov* or in hard copy at the EPA Docket Center (EPA/DC), EPA WJC West Building, Room 3334, 1301 Constitution Ave., NW, Washington, DC. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding holidays. The telephone number for the Public Reading Room is (202) 566-1744, and the telephone number for the EPA Docket Center is (202) 566-1742.

FOR FURTHER INFORMATION CONTACT: Dr. Nick Hutson, Energy Strategies Group, Sector Policies and Programs Division (D243-01), U.S. Environmental Protection Agency, Research Triangle Park, NC 27711; telephone number: (919) 541-2968; email address: *hutson.nick@epa.gov*.

SUPPLEMENTARY INFORMATION: *Submitting CBI*. Do not submit information that you consider to be CBI electronically through *http://www.regulations.gov* or email. Send or deliver information identified as CBI to only the following address: OAQPS Document Control Officer

(Room C404-02), Environmental Protection Agency, Research Triangle Park, North Carolina 27711; Attn: Docket ID No. EPA-HQ-OAR-2017-0545.

Clearly mark the part or all of the information that you claim to be CBI. For CBI information in a disk or CD-ROM that you mail to the EPA, mark the outside of the disk or CD-ROM as CBI and then identify electronically within the disk or CD-ROM the specific information that is claimed as CBI. In addition to one complete version of the comment that includes information claimed as CBI, a copy of the comment that does not contain the information claimed as CBI must be submitted for inclusion in the public docket. If you submit a CD-ROM or disk that does not contain CBI, mark the outside of the disk or CD-ROM clearly that it does not contain CBI. Information marked as CBI will not be disclosed except in accordance with procedures set forth in 40 Code of Federal Regulations (CFR) part 2.

Organization of This Document. The following outline is provided to aid in locating information in this preamble.

I. General Information

A. What is the purpose of this ANPRM?

An ANPRM is an action intended to solicit information from the public in order to inform the EPA as the Agency considers whether to commence a rulemaking. In light of the proposed repeal of the CPP [cite], this ANPRM focuses on considerations pertinent to a potential new rule establishing emission guidelines for GHG (as CO_2)[1] emissions from existing EGUs. In this ANPRM, the EPA sets out, and requests comment on, the roles, responsibilities, and limitations of the federal government, state governments, and regulated entities in developing and implementing such a rule, and the EPA solicits information regarding the appropriate scope of such a rule and associated technologies and approaches.

B. Executive Summary

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[1] The air pollutant of interest in this ANPRM is greenhouse gases. However, any emission guidelines in a potential rule would be expressed as guidelines to limit emissions of CO_2 as it is the primary GHG emitted from fossil fuel-fired EGUs.

The EPA, like all federal agencies, is a creature of statute whose powers are limited to those duly delegated to it by statute. The CAA dictates whatever authority the agency possesses to control GHG emissions from existing fossil-fueled EGUs. The CAA in its opening section acknowledges that control of air pollution at its source is primarily the responsibility of state and local governments, and EPA will interpret section 111(d) in keeping with the statute's animating principle of cooperative federalism. Recognizing the localized impacts of environmental regulations, the CAA relies heavily on cooperative federalism to achieve its environmental and public health goals and, for several key programs, provides that States will have the primary role in deciding who gets regulated and the scope of that regulation. While the CAA is a source of authority, it is also a source of carefully crafted limitations, which this agency must and will respect.

Consistent with this approach, the Agency conducted its review of the CPP as directed by Executive Order 13783, and has proposed that a rescission of the CPP is appropriate on the basis of the agency's reinterpretation of the statutory provisions underlying it. More specifically, the agency proposed to determine that the CPP is premised on an improperly expansive view of the CAA that exceeds the authority granted to the agency under section 111(d). Accordingly, on October XX, 2017, the United States EPA proposed a rule to repeal the CPP.

With the proposed repeal of the CPP, EPA must now ascertain the scope of legal authority that Congress conferred to EPA through the CAA to control GHG emissions from existing EGUs. Once the Agency determines the scope of this authority, then the Agency must determine how best to implement a policy that is consistent with the statute. This ANPRM provides notice that the agency is considering the scope of legal authority to propose a rule to

reduce CO_2 emissions from existing fossil-fueled EGUs and solicits information for the Agency to consider in developing such a rule.

CAA section 111 provides the legal framework and basis for the type of potential rule at issue in this notice. When issuing a rule under that section, the EPA must establish emission guidelines that reflect the best system of emission reduction (BSER) that has been adequately demonstrated for existing sources in the relevant source category (or categories), with consideration of the cost of achieving those reductions and any non-air quality health and environmental impacts and energy requirements. Each State then develops a plan with its own legally enforceable emission standards to implement the emission guidelines, with flexibility to accommodate the State's particular needs and circumstances in developing a compliance plan. Through this ANPRM, the EPA solicits information on systems of emission reduction which are limited to emission-reduction measures that can be applied to or at a stationary source. For example, as discussed more fully in this document, the EPA is interested in comments regarding the potential for use of measures to improve heat rates of both utility boilers and combustion turbines; and application of advanced-coal technologies, including carbon capture and storage (CCS), to fossil fuel-fired EGUs.

In this ANPRM, the EPA is also soliciting comment on applicability criteria for source categories and subcategories; and potential interactions with other regulatory programs, such as NSR.

The EPA actively promotes cooperative federalism and acknowledges that States are in the best position to determine their most appropriate approaches to reduce emissions. To that end, as discussed in this ANPRM, the EPA solicits comment on how the agency should review and act on States' plan submittals, the appropriateness and usefulness of the EPA providing

sample state plan text, and treatment by the EPA of States' existing plans or regulatory programs to reduce CO_2 emissions, among other considerations.

C. Where can I get a copy of this document?

In addition to being available in the docket, an electronic copy of this ANPRM will also be available on the Internet. Following signature by the EPA Administrator, a copy of this ANPRM will be posted at the following address: *https://www.epa.gov/Energy-Independence*. Following publication in the **Federal Register**, the EPA will post the **Federal Register** version of the ANPRM and key technical documents at this same Web site.

II. Background

In accordance with Executive Order 13783, 82 FR 16,093 (Mar. 31, 2017), the EPA has reviewed the CPP and issued a notice of proposed repeal on October XX, 2017. As discussed in that notice, the EPA proposes a change in the legal interpretation underlying the CPP to an interpretation that is consistent with the text, context, structure, purpose, and legislative history of the CAA, as well as with the agency's historical understanding and exercise of its statutory authority. If the proposed interpretation is finalized, the CPP would be repealed. The EPA also explains in that notice of proposed repeal that the agency is considering the scope of its legal authority to issue a potential new rule and is soliciting information on systems of emission reduction that are in accord with the legal interpretation proposed in that notice and information on compliance measures and state-planning requirements.

III. The Statutory and Regulatory Framework under CAA Section 111

A. The EPA's Interpretation of CAA Section 111(a)(1)

In the CPP Repeal Proposal, the EPA explained that the Administrator proposes to return to the traditional reading of CAA section 111(a)(1) as being limited to emission reduction

measures that can be *applied to or at* a stationary source. Under this reading, such measures must be based on a physical or operational change to a building, structure, facility, or installation at that source, rather than measures that the source's owner or operator *can implement on behalf of* the source at another location. The EPA is not soliciting comment through this ANPRM on this proposed interpretation; rather, comments on interpreting CAA section 111(a)(1) should be submitted on the CPP Repeal Proposal.

B. The EPA's Role and Responsibilities under CAA Section 111(d)

The EPA has certain responsibilities to fulfill and authority to act when issuing a rule under CAA section 111(d). Specifically, the EPA is required to prescribe regulations establishing a procedure under which States submit plans that establish standards of performance for existing sources and that provide for the implementation and enforcement of such standards. The EPA's regulations implementing section 111(d) created a process by which the EPA issues "emission guidelines" reflecting the Administrator's judgment on the degree of control attainable with the BSER that has been adequately demonstrated for existing sources in relevant source categories. The EPA has set emission guidelines consistent with this approach for six source categories under CAA section 111(d). These earlier emission guidelines shared a number of common features or elements:

- A description of the BSER that has been adequately demonstrated based on controls or actions that could be implemented within-the-fence-line.
- A consideration of the degree of emission limitation achievable, taking into account costs and energy and environmental impacts from the application of the BSER.
- A compliance schedule.
- A level or degree of emission reductions achievable with application of the BSER.
- Rule language implementing the emission guideline.
- Other information to facilitate the development of state plans.

Once the EPA issues an emission guideline, States develop CAA section 111(d) plans establishing standards of performance for the covered sources within their borders and providing procedures for the implementation and enforcement of such standards. The state plans are submitted to the EPA for review and approval or disapproval through notice-and-comment rulemaking. In cases where a State fails to submit a "satisfactory" plan, the EPA has authority to prescribe a plan for that State. Where a State fails to enforce an EPA-approved plan, the EPA has the authority to enforce the provisions of such a plan.

The EPA is taking comment on how best to define the BSER and developing emission guidelines for EGUs for emissions of CO_2. Specifically, we are requesting comment on the following two subjects:

(1) Identifying the BSER that can be implemented within-the-fence-line of an affected source (section IV below discusses what such a BSER might look like in more detail).

(2) Whether emission guidelines for EGUs for emissions of CO_2 should include presumptively approvable limits.

1. "Within-the-fence-line" BSER

The EPA's traditional approach to establish the BSER focused on technological or operational measures that can be applied to or at a single source. The agency is now requesting comment on how to take an approach to regulating GHG from existing EGUs in line with its prior practice under section 111(d) whereby it would consider only "within-the-fence-line" measures to develop the BSER and emission guidelines. The types of measures that may be considered for a "within-the-fence-line" construction of the BSER that is adequately demonstrated are discussed in more detail below in Section IV.

2. Presumptively Approvable Limits

As discussed in section IV of this document, with regard to coal-fired EGUs, the potential for emission reductions at the unit-level or within-the-fence-line of the facility may vary widely from unit to unit. Consequently, broadly applicable, presumptively approvable emission limitations (even at a subcategorized level) may not be appropriate for CO_2 emissions from EGUs. Therefore, in this ANPRM, the EPA is taking comment on an approach where the agency provides emission guidelines without providing a presumptively approvable emission limitation.

C. States' Role and Responsibilities under CAA Section 111(d)

1. Designing State Plans

Subpart B of 40 CFR part 60 sets forth the procedures and requirements for States' submittal of, and EPA's action on, state plans for control of designated pollutants from designated facilities under section 111(d) of the CAA (we refer to these as the "implementing regulations"). A summary of subpart B and a discussion of the basic concepts underlying it appear in the preamble published in connection with its promulgation (40 FR 53340, November 17, 1975). In brief, subpart B provides that after a standard of performance applicable to emissions of a designated pollutant from new sources is promulgated, the Administrator will publish a draft guideline document containing information pertinent to the control of the same pollutant from designated (*i.e.*, existing) facilities. The Administrator will also publish a notice of availability of the draft guideline document, and invite comments on its contents. After publication of a final guideline document for the pollutant in question, the States will have 9 months to develop and submit plans for control of that pollutant from designated facilities. Within 4 months after the date for submission of plans, the Administrator will approve or disapprove each plan (or portion thereof). If a State plan (or portion thereof) is disapproved, the Administrator will promulgate a federal plan (or portion thereof) within 6 months after the date

for plan submission. These and related provisions of subpart B were patterned after section 110 of the CAA and 40 CFR part 51 (concerning adoption and submittal of state implementation plans under CAA section 110).

As discussed in the preamble to subpart B of 40 CFR part 60, the implementing regulations describe flexibilities available to States in establishing state plans. For example, as provided in 40 CFR 60.24, States may consider certain factors such as cost and other limitations in setting emission standards or compliance schedules. After the implementing regulations were first promulgated, section 111(d) was amended to authorize States "to take into consideration, among other factors, the remaining useful life" of existing sources when applying standards to such sources. The EPA solicits comment on the proper application of this provision to a potential new rule addressing GHG emissions from existing EGUs, and whether any change to that provision—or to other provisions of the implementing regulations, particularly those establishing the time frames for States to submit their plans to EPA, for EPA to act on those plans, and for EPA to develop its own plan or plans in the absence of an approvable state submission—is warranted in the context of such a potential new rulemaking.

2. Application of Standards to Sources

Historically the EPA has provided States with guidance on the preparation of state plans (for example, by providing model rules or sample rule language). While providing this text provides States with a clear direction in creating their state plans, the EPA understands that it may also be perceived as sending a signal of limiting flexibility and limiting the consideration of other factors that are unique to each State and situation. The EPA is soliciting comment on whether it would be beneficial to States for the EPA to provide sample state plan text as part of the development of emission guidelines.

Each State has its own unique circumstances to consider when regulating air pollution emissions from the power industry within that State. A prime example is the remaining useful life (RUL) of the State's fleet of EGUs. A State may take into account the RUL of sources within its fleet, such as how much longer an EGU will operate and how viable it is to invest in within-the-fence-line upgrades, when establishing emission standards as part of its state plan. These are source-specific considerations and play a role in a State evaluating the future of a fleet. The EPA solicits comment on the role of a State in setting unit-by-unit or broader emission standards for EGUs within its borders, including potential advantages of such an approach (*e.g.*, it provides flexibility to tailor standards that take into account the characteristics specific to each boiler or turbine) and potential challenges (*e.g.*, the impact that varying requirements could have on emissions and dispatch in such an interconnected system). The EPA also solicits comment on an approach where the EPA determines the BSER and then allows the States to set unit-by-unit or broader emission standards based on the BSER while considering the unique circumstances of the State and the EGU. The EPA requests more information on the burden that it would create for States to determine unit-by-unit emission standards for each EGU and on what role subcategorization can play in the emission standard setting process.

The process that the State of North Carolina used in the development of its draft rule,[2] in response to the CPP, may provide a useful example of a process a State could go through to determine unit-level emission standards based on within-the-fence-line technology.[3] In that draft rule, North Carolina developed a menu of potential heat rate improvements. The State then

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[2] *https://files.nc.gov/ncdeq/Air%20Quality/rules/hearing/111dRules.pdf.*
[3] EPA is not otherwise endorsing nor judging whether this draft plan was or is adequate to meet any previous or future section 111(d) emission guidelines.

examined these potential opportunities on a unit-by-unit basis, determined that some units had opportunities for cost-effective improvements and developed unit-specific emission standards consistent with those rates. North Carolina determined that other units did not have such opportunities (for reasons including that a given heat rate improvement opportunity was not applicable to a particular unit, that it had already been applied, or that the unit was scheduled to retire soon (*i.e.*, RUL).

Another example of a unit-by-unit heat rate improvement analysis can be found in the final CAA section 111(b) Carbon Pollution Standards for modified fossil fuel-fired steam generating EGUs (80 FR 64510, October 23, 2015). There, the EPA determined that the BSER for existing steam generating EGUs that trigger the modification provisions is the affected EGU's own best potential performance as determined by that source's historical performance. Relying on this BSER, we finalized an emission standard that is based on a unit-specific emission limitation consistent with each modified unit's best 1-year historical performance and can be met through a combination of best operating practices and equipment upgrades. *See* 80 FR 64658. The EPA seeks comment on this approach to evaluate unit-specific heat rate improvement opportunities. We also seek comment on potential limitations to this approach, such as the potential for degradation of heat rate over time and the effects of changing operating conditions (*e.g.*, changing from stable baseload operations to variable load-following operations or vice-versa).

a. Rate-based and Mass-based Compliance Options and Other Potential Compliance Flexibilities

The agency's currently effective CAA section 111(d) rules were based on emission rate standards (*e.g.*, tons of pollution/unit of heat input or production). The potential opportunities for

improvements in a unit's CO_2 performance seem similarly amenable to emission rate standards. The EPA takes comment on whether a within-the-fence-line based set of emission guidelines for CO_2 emission rate standards is all that it or the States should consider in a potential future rulemaking or whether the use of mass-based emission standards should also be considered.

In addition to the form of the emission standard, the EPA solicits comment on what factors EPA should consider when reviewing state plans, as well as additional compliance flexibilities States should be able to employ in developing state plans. Should States be able to develop plans that allow emissions averaging? If so, should averaging be limited to units within a single facility, to units within a State, or to units within an operating company? If averaging is not limited between units in different States, are any special requirements needed to facilitate such trading? Should mass-based trading be considered? If so, how should rate-based compliance instruments intended to meet unit-specific emission rates be translated into mass-based compliance instruments? Should rate-based trading programs be able to interact with mass-based trading programs? What considerations should States and the EPA take into account when determining appropriate implementing and enforcing measures for emission standards? The EPA requests information and feedback on all of these questions and on what limitations, if any, apply to States as they set standards.

IV. Available Systems of CO_2 Emission Reduction

The EPA has examined "within-the-fence-line" technologies and strategies that could potentially be applied at existing EGUs to reduce emissions of CO_2. The agency primarily focused on opportunities for heat rate (or efficiency) improvements at fossil fuel-fired steam generating EGUs to be a part of the BSER.

A. Heat Rate Improvements for Boilers

1. Heat Rate Improvement

Heat rate is a measure of efficiency for fossil fuel-fired EGUs. An EGU's heat rate is the amount of energy input, measured in British thermal units (Btu), required to generate one kilowatt hour (kWh) of electricity. The more efficiently an EGU operates, the lower its heat rate will be. As a result, an EGU with a lower heat rate will consume less fuel and emit lower amounts of CO_2 and other air pollutants as compared to a less efficient unit. An EGU's heat rate can be affected by a variety of design characteristics, site-specific factors, and operating conditions, including:

- Thermodynamic cycle of the boiler.
- Boiler and steam turbine size and design.
- Cooling system type.
- Auxiliary equipment, including pollution controls.
- Operations and maintenance.
- Fuel quality.
- Ambient conditions.

The EPA has assessed the potential heat rate improvements of existing coal-fired EGUs by conducting statistical analyses using historical gross heat rate data from 2002 to 2012 for 884 coal-fired EGUs that reported both heat input and gross electricity output to the agency in 2012. The agency grouped the EGUs by regional interconnections – Western, Texas, and Eastern – and analyzed potential heat rate improvements within each interconnection. The results of the statistical analyses indicated that there may be significant potential for heat rate improvement – both regionally and nationally. However, these results represent fleet-wide average heat rate improvement. The EPA did not conduct analyses to identify heat rate improvement opportunities at the unit level and the agency recognizes that the fleet of U.S. fossil fuel-fired EGUs is varied

in terms of size, age, fuel-type, type, *etc*. The EPA solicits comment on this statistical approach and its applicability in identifying heat rate improvement opportunities at the unit level.

There are several technologies and equipment upgrades – as well as good operating and maintenance practices – that EGU owners or operators may utilize to reduce an EGU's heat rate, in particular for utility boilers. Table 1 lists some technology and equipment upgrades that owners or operators of EGUs may be able to deploy to improve heat rate. Table 2 lists some good practices that have the potential to reduce an EGU's heat rate. (Note, these lists of technologies and practices, along with their respective potential heat rate improvements, were drawn from studies listed below in Table 3.)

The EPA is seeking comment on the technologies and practices listed in Tables 1 and 2. Specifically, the agency is interested in the availability and applicability of these technologies and best operating and maintenance practices for the U.S. fossil fuel-fired EGU fleet. We are also soliciting comment on potential heat rate improvements from these technologies and practices; on likely costs of deploying these technologies and the good operating and maintenance practices, including applicable planning, capital, and operating and maintenance costs; on owner and operator experiences deploying these technologies and employing these operating and maintenance practices; on barriers to or from deploying these technologies and operating and maintenance practices; and on any other technologies or operating and maintenance practices that may exist for improving heat rate, but are not reflected on these lists.

Table 1 – Example Equipment Upgrades and Technology to Improve Heat Rates at Utility Boilers

Equipment upgrade(s)	Potential heat rate improvement
Replace materials handling motors and drives with more efficient motors	Negligible

and / or variable frequency drives to reduce ancillary energy consumption.	
Improve coal pulverizers to produce more finely ground coal to improve combustion efficiency.	Negligible
Use waste heat to dry low-grade coal and improve combustion efficiency.	N/A
Convert from a water sluicing bottom ash system to a dry drag chain ash system to reduce ancillary energy consumption.	Negligible
Automate boiler drains to manage make-up water intake.	N/A
Improve boiler, furnace, ductwork, and pipe insulation to reduce heat loss.	N/A
Upgrade economizer to increase heat recovery.	50-100 Btu/kWh
Install a neural network and advanced sensors and controls to optimize plant station operation.	0-150 Btu/kWh
Install intelligent sootblowers to enhancing furnace efficiency.	30-150 Btu/kWh
Improve seals on regenerative air pre-heaters to reduce air in-leakage and increase heat recovery.	10-40 Btu/kWh
Install sorbent injection system to reduce flue gas sulfuric acid content and allow increased energy recovery at the air heater.	50-120 Btu/kWh
Upgrade steam turbine internals to improve efficiency and replace worn seals to reduce steam leakage.	100-300 Btu/kWh
Retube the condenser to restore efficiency or expand condenser surface area to improve efficiency.	3-70 Btu/kWh
Replace feedwater pump seals to reduce water loss.	N/A
Install solar systems to pre-heat feedwater to improve efficiency.	N/A
Increase feedwater heating surface to improve efficiency.	N/A
Overhaul or upgrade boiler feedwater pumps to improve efficiency.	25-50 Btu/kWh
Replace centrifugal induced draft (ID) fans with axial ID fans.	10-50 Btu/kWh
Replace ID fan motors with variable frequency drives.	10-150 Btu/kWh
Upgrade flue-gas desulfurization components (*e.g.*, co-current spray tower quencher, turning vanes, variable frequency drives) to reduce pressure drop, improve flow distribution, and reduce ancillary energy consumption.	0-50 Btu/kWh
Upgrade the electrostatic precipitator energy system (*e.g.*, high voltage transformer/rectifier sets) to improve particulate matter capture and reduce energy consumption.	0-5 Btu/kWh
Replace older motors with more efficient motors to reduce ancillary energy consumption.	0-21 Btu/kWh
Refurbish and/or upgrade cooling tower packing material to improve cycle efficiency.	0-70 Btu/kWh
Install condenser tube cleaning system to reduce scaling, improve heat transfer and restore efficiency.	N/A

N/A = not available.

Table 2 – Example Good Practices to Improve Heat Rates at Utility Boilers

Good practice(s)	Potential heat

	rate improvement
Reduce excess air to improve combustion efficiency.	N/A
Optimize primary air temperature to improve combustion efficiency.	N/A
Measure and control primary and secondary air flow rates to improve combustion efficiency.	N/A
Tune individual burners (balance air/fuel ratio) to improve combustion efficiency.	N/A
Conduct more frequent condenser cleanings to maintain cycle performance.	30-70 Btu/kWh
Monitor condenser performance to track efficiency/performance.	N/A
Use secondary air for ammonia vaporization and dilution to reduce ancillary energy consumption.	0-5 Btu/kWh
Careful monitoring of the water treatment system for optimal feedwater quality and cooling water performance to reduce scale build-up and corrosion plus maintain efficiency.	N/A
Conduct maintenance of cooling towers (*e.g.*, replace missing/damaged planks) to restore cooling tower efficiency.	N/A
Chemical clean scale build-up on feedwater heaters to improve heat transfer.	N/A
Repair steam and water leaks (*e.g.*, replace valves and steam traps) to reduce makeup water consumption.	N/A
Repair boiler, furnace, ductwork, and air heater cracks to reduce air in-leakage and auxiliary energy consumption.	N/A
Clean air pre-heater to improve heat transfer.	N/A
Adopt sliding pressure operation to reduce turbine throttling losses.	N/A
Reduce attemperator activation to reduce heat input.	N/A
Clean turbine blades to remove deposits and improve turbine efficiency.	N/A
Maintain instrument calibration to ensure valid operating data.	N/A
Perform on-site appraisals to identify areas for improved heat rate performance.	N/A
Adopt training program for operating and maintenance staff on heat rate improvements.	N/A
Adopt incentive program to reward actions to improve heat rate.	N/A
Improve performance monitoring and information.	N/A
Implement heat rate analytics to identify real-time heat rate deviations.	N/A
Plant lighting upgrades to reduce ancillary energy consumption.	N/A
Use predictive maintenance to avoid outages and de-rate events.	N/A

N/A = not available.

The technologies and operating and maintenance practices listed above may not be available or appropriate for all types of EGUs; and some owners or operators may have already deployed some of the technologies and/or employed some of the best operating and maintenance

practices at their fossil fuel-fired EGUs. In addition, some of the technologies and operating and maintenance practices listed above might be alternatives to other actions on the list and, therefore, mutually exclusive of other technologies and practices.

Government agencies and laboratories, industry research organizations, engineering firms, equipment suppliers, and environmental organizations have conducted studies examining the potential for improving heat rate in the U.S. EGU fleet or a subset of the fleet. Table 3 provides a list of some reports, case studies, and analyses about heat rate improvement opportunities in the U.S. The EPA is seeking comment on the appropriateness of the studies for informing our understanding of potential heat rate improvement opportunities. The EPA is also seeking information on any additional publicly available studies that identify heat rate improvement measures or demonstrate actual or potential heat rate improvements at fossil fuel-fired EGUs, including the appropriateness of the studies for establishing heat rate improvement goals.

Table 3 – Heat Rate Improvement Reports, Case Studies, and Analyses

Heat rate improvement report organization/publication (author, if known) – title – year [URL]
Alstom Engineering (Sutton) – CO_2 Reduction Through Energy Efficiency in Coal Fired Boilers – 2011 [*http://www.mcilvainecompany.com/Universal_Power/Subscriber/PowerDescriptionLinks/Jim%20Sutton%20-%20Alstom%20-%203-31-2011.pdf*]
Congressional Research Service (Campbell) – Increasing the Efficiency of Existing Coal-fired Power Plants (R43343) – 2013 [*https://fas.org/sgp/crs/misc/R43343.pdf*]
EIA – Analysis of Heat Rate Improvement Potential at Coal-Fired Power Plants – 2015 [*https://www.eia.gov/analysis/studies/powerplants/heatrate/pdf/heatrate.pdf*]
EPA – Greenhouse Gas Mitigation Measures – 2015 [*https://www.regulations.gov/document?D=EPA-HQ-OAR-2013-0602-37114*]
EPRI – Range of Applicability of Heat Rate Improvements – 2014 [*https://www.epri.com/#/pages/product/000000003002003457*]
European Commission – Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants – 2006 [*http://eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf*]

GE – Comments of the General Electric Company – 2014 [*https://www.regulations.gov/document?D=EPA-HQ-OAR-2013-0602-22971*]
IEA (Reid) – Retrofitting Lignite Plants to Improve Efficiency and Performance (CCC/264) – 2016 [*http://bookshop.iea-coal.org/reports/ccc-264/83861*]
IEA (Henderson) – Upgrading and Efficiency Improvement in Coal-fired Power Plants (CCC/221) – 2013 [*http://bookshop.iea-coal.org/reports/ccc-221/83186*]
Lehigh University – Reducing Heat Rates of Coal-fired Power Plants – 2009 [*http://www.lehigh.edu/~inenr/leu/leu_61.pdf*]
NETL – Opportunities to Improve the Efficiency of Existing Coal-fired Power Plants – 2009 [*http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Publications/OpportImproveEfficExistCFPP-ReportFinal.pdf*]
NETL – Improving the Thermal Efficiency of Coal-Fired Power Plants in the United States – 2010 [*http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Publications/ThermalEfficCoalFiredPowerPlants-TechWorkshopRpt.pdf*]
NETL – Improving the Efficiency of Coal-Fired Power Plants for Near Term Greenhouse Gas Emissions Reductions (DOE/NETL-2010/1411) – 2010 [*http://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Publications/DOE-NETL-2010-1411-ImpEfficCFPPGHGRdctns-0410.pdf*]
National Petroleum Council – Electric Generation Efficiency – 2007 [*http://www.npc.org/Study_Topic_Papers/4-DTG-ElectricEfficiency.pdf*]
NRDC – Closing the Power Plant Carbon Pollution Loophole: Smart Ways the Clean Air Act Can Clean Up America's Biggest Climate Polluters (12-11-A) – 2013 [*https://www.nrdc.org/sites/default/files/pollution-standards-report.pdf*]
Power Mag (Korellis) – Coal-Fired Power Plant Heat Rate Improvement Options, Parts 1 & 2 – 2014 [*http://www.powermag.com/coal-fired-power-plant-heat-rate-improvement-options-part-1*] [*http://www.powermag.com/coal-fired-power-plant-heat-rate-improvement-options-part-2*]
Power Mag (Peltier) – Steam Turbine Upgrading: Low-hanging Fruit – 2006 [*http://www.powermag.com/steam-turbine-upgrading-low-hanging-fruit*]
Resources for the Future (Lin et al) – Regulating Greenhouse Gases from Coal Power Plants Under the Clean Air Act (RFF-DP-13-05) – 2014 [*http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-13-05.pdf*]
S&L – Coal-fired Power Plant Heat Rate Reductions (SL-009597) – 2009 [*https://www.regulations.gov/document?D=EPA-HQ-OAR-2013-0602-36895*]
Sierra Club (Buckheit & Spiegel) – Sierra Club 52 Unit Study – 2014 [*http://content.sierraclub.org/environmentallaw/sites/content.sierraclub.org.environmentallaw/files/Appendix%201%20-%20Rate%20v%20Load%20Summary.pdf*]
Storm Technologies – Applying the Fundamentals for Best Heat Rate Performance of Pulverized Coal Fueled Boilers – 2009 [*http://www.stormeng.com/pdf/EPRI2009HeatRateConference%20FINAL.pdf*]

2. Measuring Heat Rate at Fossil Fuel-Fired EGUs

Accurately monitoring changes in heat rate is vital for assessing the degree of heat rate improvement at fossil fuel-fired EGUs. Most coal-fired EGUs already continuously monitor heat input and gross electric output and report the information to the EPA under 40 CFR part 75. To calculate heat input, coal-fired EGUs monitor the CO_2 concentration and stack volumetric flow rates. Part 75 classifies hourly CO_2 concentration and stack volumetric flow rates measurements as valid, if the continuous emissions monitoring systems' (CEMS') relative accuracies are within plus or minus 10 percent when compared to federal reference methods.

In 1999, the EPA introduced new federal reference methods to address angular stack flow (Methods 2F and 2G) and the effect of the stack walls on gas flow (Method 2H). In general, these alternative measurement methods reduce or eliminate the over-estimation of stack gas volumetric flow that results from the use of method 2 when specific flow conditions (*e.g.,* angular flow) are present in the stack. Generally, the alternative methods lead to lower flow rates, and, as a result, lower heat input. After the introduction of these new methods, many coal-fired EGUs adopted the alternative methods to measure flow and calculate mass emissions. However, coal-fired EGUs are not required to use the alternative measurement methods, and they may change methods when conducting a Relative Accuracy Test Audit (RATA).

The EPA is seeking comment on the level of uncertainty of measurement of flue gas CO_2 concentration and stack volumetric flow rate; options to reduce the uncertainty associated with CEMS at coal-fired EGUs and fuel flow monitors (40 CFR part 75, appendix D) and 40 CFR part 75, appendix G, equation G-4 at natural gas- and oil-fired EGUs; options for eliminating or revising 40 CFR part 75, appendix G, equation G-1 at natural gas- and oil-fired EGUs; and alternative approaches to accurately measure heat rate at fossil fuel-fired EGUs.

B. Heat Rate Improvements at Natural Gas-fired Combustion Turbines

The EPA has also considered opportunities for within-the-fence-line emission reductions at natural gas-fired stationary combustion turbines – at both simple cycle turbines and combined cycle turbines – and determined that the available emission reductions would likely be too expensive or would likely provide only small overall reductions. In the development of the CAA section 111(b) standards of performance for new, modified, and reconstructed EGUs, several commenters provided information on various options that may be available to improve the efficiency of existing natural gas-fired stationary combustion turbines. *See* 80 FR 64620. Commenters – including turbine manufacturers – described specific technology upgrades for the compressor, combustor, and gas turbine components that operators of existing combustion turbines may deploy. These state-of-the-art gas path upgrades, software upgrades, and combustor upgrades can reduce CO_2 emissions by 2.8 percent. In addition, one turbine manufacturer stated that existing combustion turbines can achieve the largest efficiency improvements by upgrading existing compressors with more advanced compressor technologies, potentially improving the combustion turbine's efficiency by an additional 3.8 percent. Thus, the total potential CO_2 emissions reductions for just the combustion turbine portion of a combined cycle unit is 6.6 percent.

In addition to upgrades to the combustion turbine, the operator of a natural gas combined cycle (NGCC) unit will have the opportunity to improve the efficiency of the heat recovery steam generator and steam cycle using retrofit technologies that may reduce the CO_2 emissions by 1.5 to 3 percent. These include (1) steam path upgrades that can minimize aerodynamic and steam leakage losses; (2) replacement of the existing high pressure turbine stages with state-of-the-art stages capable of extracting more energy from the same steam supply; and (3)

replacement of low-pressure turbine stages with larger diameter components that extract additional energy and that reduce velocities, wear, and corrosion.

The EPA seeks comment on the broad availability and applicability of any heat rate (efficiency) improvements for natural gas combustion turbine EGUs including, but not limited to, those discussed in this ANPRM. We also seek comment on the agency's previous determination that the available emission reduction opportunities would likely be too expensive or would likely provide only small overall reductions.

C. Other Available Systems of Emission Reduction

1. Broad Solicitation of Information on Other Available Systems of Emission Reduction

The EPA is interested in obtaining information on any other systems of CO_2 emission reductions that may be available for consideration as the BSER for existing fossil fuel-fired EGUs. The EPA is also interested in obtaining information on available systems of emission reduction that may not meet the criteria for consideration as the BSER (because, for example, they may not be broadly applicable), but are emission reduction options that may be considered as compliance options for individual units.

The agency solicits information on any system of emission reduction that commenters believe to be available and applicable for reducing emissions of CO_2 from existing fossil fuel-fired steam-generating EGUs (*i.e.*, utility boilers and integrated gasification combined cycle (IGCC) units) and/or combustion turbines (*e.g.*, NGCC units). The agency seeks information on all aspects of the systems of emission reduction – including the availability, applicability, technical feasibility, and the cost of any such systems of emission reduction. The EPA also seeks information on any limitations to the application of systems of emission reduction. In particular, the agency is interested in whether there are geographic limitations to the applicability of

suggested emission reduction systems. The agency also notes that the current fleet of existing EGUs is quite diverse in terms of generating technology, size, location, age, fuel usage, and configuration. The EPA is interested in obtaining information on any limitations on the use of emission reduction systems that are due to the diverse nature of the existing fleet of EGUs. For example, are any potential emission reduction systems limited by geographic location? Are any potential systems of emission reduction limited to use with only certain fossil fuels or certain coal types?

2. Carbon Capture and Storage (CCS)

The EPA has previously determined that CCS (or partial CCS) should not be a part of the BSER for existing fossil fuel-fired EGUs because it was not widely available and it was significantly more expensive than alternative options for reducing emissions. The EPA continues to believe that neither CCS nor partial CCS are broadly applicable technologies that can be considered as BSER for existing fossil fuel-fired EGUs.

However, the agency recognizes that some companies may be interested in using CCS technology as a compliance option – especially when they are able to use the captured CO_2 in enhanced oil recovery operations (*e.g.*, the W. A. Parish Plant in Texas). The EPA solicits information on how potentially affected EGUs may utilize retrofit CCS technology as a compliance option to reduce CO_2 emissions and whether those EGUs should be allowed to participate in any intrastate or interstate trading program. The agency also seeks information on the appropriate level of monitoring, recordkeeping, and reporting that should be required for sequestered CO_2 in such cases. In the final carbon standards issued under CAA section 111(b), the EPA requires new fossil fuel-fired EGUs to limit CO_2 emissions and identifies partial CCS as one of the compliance options. In that final rule, any new affected EGU that uses CCS to meet

the applicable CO_2 emission limit must report in accordance with 40 CFR part 98, subpart PP (Suppliers of Carbon Dioxide), and the captured CO_2 must be injected at a facility or facilities that reports in accordance with 40 CFR part 98, subpart RR (Geologic Sequestration of Carbon Dioxide). *See* 40 CFR 60.46Da(h)(5) and 40 CFR 60.5555(d). Together, these requirements ensure that the amount of captured and sequestered CO_2 will be tracked as appropriate at project and national levels and that the status of the CO_2 in its geologic storage site will be monitored, including air-side monitoring and reporting. The EPA solicits comment on this approach and other alternatives that may be used when utilizing CCS as a compliance option for meeting emission reduction requirements in a state plan.

D. Source Categories and Subcategories

1. Applicability Criteria

The EPA has specified that an affected EGU is any existing fossil fuel-fired electric utility steam generating unit (*i.e.*, utility boiler or IGCC unit) or stationary combustion turbine that meets specific criteria. An affected EGU (either steam generating or stationary combustion turbine) must serve a generator capable of selling more than 25 megawatts to a utility power distribution system and have a base load heat input rating greater than 250 million Btu per hour. An affected stationary combustion turbine EGU must meet the definition of a combined cycle or combined heat and power combustion turbine. EPA has also specifically exempted certain EGUs from applicability, including simple cycle turbines, certain non-fossil units, and certain combined heat and power units. *See* 80 FR 64716. The EPA solicits comment on applicability criteria in a potential new rule and whether the agency should retain the criteria and exemptions previously set forth.

2. Subcategories

CAA section 111 requires the EPA first to list source categories that may reasonably be expected to endanger public health or welfare and then to regulate new sources within each of those source categories. The agency has discretion, provided in CAA section 111(b)(2), to "distinguish among classes, types, and sizes within categories of new sources for the purpose of establishing [new source] standards." We refer to these distinctions as "subcategories." CAA section 111(d)(1) is silent on whether the EPA may establish subcategories for existing sources, but the EPA has interpreted this provision to authorize the EPA to exercise discretion as to whether and, if so, how to subcategorize existing sources subject to CAA section 111(d). Further, the implementing regulations under CAA section 111(d) provide that the Administrator will specify different emission guidelines or compliance times or both "for different sizes, types, and classes of designated facilities when costs of the control, physical limitations, geographical location, or similar factors make subcategorization appropriate."[4]

In previous rulemakings, the EPA has promulgated presumptive EGU-related emission standards for subcategories of sources. For example, the EPA has issued separate NSPS for sulfur dioxide and NOx emissions from EGUs that utilize coal refuse as a subcategory of steam generating EGUs that utilize coal or other fossil fuel. *See* 77 FR 9423. The EPA has also promulgated separate standards of performance that distinguish between stationary combustion turbines that operate to provide intermediate and baseload power demand as opposed to those that operate to provide peak power demand. The EPA has also issued separate standards based on coal-type. For example, in the Mercury and Air Toxics Standards (MATS), promulgated

[4] 40 CFR 60.22(b)(5).

under CAA section 112(d)(1),[5] the agency issued separate mercury emission standards for coal-fired EGUs that use lignite versus those that use non-lignite coal. The agency, also in the MATS rule, promulgated separate emission standards for IGCC EGUs as compared to the standards issued for utility boilers. *See* 77 FR 9487. The agency solicits comment on whether potentially affected EGU sources (*e.g.*, steam generating EGUs, stationary combustion turbines) should be grouped into categories and subcategories for purposes of identifying the BSER. Commenters are requested to provide justification for such subcategorization. For example, are emissions and emission reduction opportunities distinct for EGUs of different sizes, classes, or types – or for EGUs utilizing different types or qualities of fossil fuels? The EPA requests comment on subcategorization based on operation or utilization of the EGU – *i.e.*, based on whether the EGU (whether a utility boiler, an IGCC unit, or a stationary combustion turbine) is operated to serve baseload, intermediate, or peak power demand.

V. Potential Interactions with Other Regulatory Programs

A. New Source Review (NSR)

The NSR program is a preconstruction permitting program that requires stationary sources of air pollution to obtain permits prior to beginning construction. The NSR program applies both to new construction and to modifications of existing sources. New construction and modifications that emit air pollutants over certain thresholds are subject to major NSR requirements, while smaller emitting sources and modifications may be subject to minor NSR

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[5] CAA section 112(d)(1) provides that "The Administrator may distinguish among classes, types, and sizes of sources within a category or subcategory in establishing such standards …."

requirements.[6] Major NSR permits for sources in attainment areas and for other pollutants regulated under the major source program are referred to as prevention of significant deterioration (PSD) permits, while major NSR permits for sources emitting nonattainment pollutants and located in nonattainment areas are referred to as nonattainment NSR (NNSR) permits.

Since emission guidelines that are established pursuant to CAA section 111(d) apply to units at existing sources, the interaction between section 111(d) and the NSR program primarily centers around the treatment of modifications of existing sources. Generally, a major stationary source triggers major NSR permitting requirements when it undertakes a physical or operational change that results in (1) a significant emission increase at the emissions unit, and (2) a significant net emissions increase at the source (*i.e.*, a source-wide "netting" analysis that considers emission increases and decreases occurring at the source during a contemporaneous period). *See, e.g.*, 40 CFR 52.21(b)(2)(i). NSR regulations define what emissions rate on an annual tonnage basis constitutes "significant" for NSR pollutants. *See, e.g.*, 40 CFR 52.21(b)(23).[7] For example, an increase in emissions is "significant" for NO_x when it is at least

[6] Major sources and certain other sources are also required by the CAA to obtain title V operating permits. While title V permits generally do not establish new emissions limits, they consolidate requirements under the CAA into a comprehensive air permit.

[7] In the case of GHGs, EPA regulations currently do not have a "significant" emissions rate. Under existing regulations, a major source would trigger PSD permitting requirements for GHG if it undergoes a modification that results in a significant increase in the emissions of a pollutant other than GHGs and a GHG emissions increase of 75,000 tons per year of carbon dioxide equivalent (CO_2e) as well as a GHG emissions increase (*i.e.*, anything above zero) on a mass basis. In proposing a significant emissions rate for GHG, the EPA has proposed to remove the mass-based component of the NSR emissions test for GHG. *See* 81 FR 68110 (October 3, 2016). Furthermore, in *UARG v. EPA,* 134 S. Ct. 2427 (June 23, 2014), the U.S. Supreme Court held that an increase in GHG emissions alone cannot by law trigger the NSR requirements of the PSD program under section 165 of the CAA. Thus, unlike other NSR pollutants, a modification that

40 tons per year. To calculate the emissions increase from a project, the “projected actual emissions” (PAE) are compared to the “baseline actual emissions” (BAE). For EGUs, the PAE is the maximum annual rate (tons per year) that the modified unit is projected to emit a pollutant in any one of the 5 years (or 10 years if the design capacity increases) after the project, excluding any increase in emissions that (1) is unrelated to the project, and (2) could have been accommodated during the baseline period (commonly referred to as the “demand growth exclusion”). The BAE for an EGU is the average annual rate of actual emissions during any 2-year period within the last 5 years.

If a physical or operational change triggers the requirements of the major NSR program, the source must obtain a permit prior to making the change. The pollutant(s) at issue and the air quality designation of the area where the facility is located or proposed to be built determine the specific permitting requirements. The CAA requires sources to install best available control technology (BACT) for PSD permits and Lowest Achievable Emissions Rate (LAER) for NNSR permits. CAA sections 165(a)(4), 173(a)(2). These technology requirements for major NSR permits are not predetermined by a rule or state plan, but are case-specific decisions made by the permitting agency. Other requirements to obtain a major NSR permit vary depending on whether it is a PSD or NNSR permit and a state or a federal permit action.

New sources and modifications that do not require a major NSR permit generally require a minor NSR permit prior to construction. Minor NSR permits are almost exclusively issued by state and local air agencies, and since the CAA is less prescriptive regarding requirements for these permits, agencies have more flexibility to design their own programs.

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increases only GHG emissions above the applicable level will not trigger the requirement to obtain a PSD permit.

The EPA's regulations offer flexible permitting approaches that enable sources undergoing modifications to avoid triggering major NSR. In the case of Plantwide Applicability Limits (PALs), a source that plans to make modifications to its emission units can avoid major NSR requirements for 10 years as long as it obtains a PAL permit and operates within the source-wide emissions cap of the PAL. *See, e.g.*, 40 CFR 52.21(aa). In addition, sources can take enforceable limits on hours of operation in order to avoid triggering major NSR requirements that would otherwise apply to the source. Specifically, a source may voluntarily obtain a synthetic minor source limitation – *i.e.*, a legally and practicably enforceable restriction that has the effect of limiting emissions below the relevant major source level – to avoid triggering major NSR requirements.

Over the years, some stakeholders have expressed concerns that NSR regulations do not adequately allow for some sources to undertake changes to improve their operational efficiency without being "penalized" by having to get a major NSR permit. In the context of EGUs, stakeholders have asserted that heat rate improvement projects will often result in greater unit availability and increase in dispatching, which under the NSR program translate into projected increases in emissions that trigger major NSR permitting. Stakeholders have raised similar concerns regarding modifying an EGU facility to enable co-firing of natural gas or other lower emitting fuels.

The EPA received a number of similarly focused comments following proposal of the CPP. Specifically, commenters contended that, if an air agency, as part of its plan to comply with emission guidelines established pursuant to CAA section 111(d), requires a source to make modifications (*e.g.*, heat rate improvement projects targeted for Building Block 1), it could potentially trigger major NSR requirements. Commenters added that the EPA has previously

taken enforcement action against sources making such modifications without getting a major NSR permit.

Since this ANPRM solicits input on a possible rule that is based on actions that could be implemented within-the-fence-line of a source, we are again inviting comment from interested stakeholders on the topic of how the NSR program overlays with emission guidelines established under CAA section 111(d). We are interested in actions that can be taken to harmonize and streamline the NSR applicability and/or the NSR permitting process with a potential new rule. We invite comment on the following questions:

1. Under what scenarios would EGUs be potentially subject to the requirements of the NSR program as a result of making physical or operational changes that are part of a strategy for regulating existing sources under CAA section 111(d)? Do the scenarios differ depending on site specific factors, such as the size or class of EGU, how the EGU operates (*e.g.*, baseload, intermediate, load following), fuel(s) the EGU burns, or the EGU's existing level of pollution control? If so, please explain the differences.

2. What rule or policy changes or flexibilities can the EPA provide as part of the NSR program that would enable EGUs to implement projects required under a CAA section 111(d) plan and not trigger major NSR permitting while maintaining environmental protections?

3. What actions can sources take – *e.g.*, through the minor NSR program, agreeing to a PAL – when making heat rate improvements or co-firing with a lower emitting fuel that would allow them to continue to serve the demand of the grid while not having excessive permitting requirements?

4. What approaches could be used in crafting CAA section 111(d) plans so as to reduce the number of existing sources that will be subject to NSR permitting? Do compliance measures, such as inter- and intra-state trading systems, rate-based or mass-based standards, or generation shifting to lower- or zero-emitting units, offer favorable solutions for air agencies and sources with regard to NSR permitting?

5. What other approaches would minimize the impact of the NSR program on the implementation of a performance standard for EGU sources under CAA section 111(d)?

B. New Source Performance Standards (NSPS)

The EPA solicits comment on whether there are any potential interactions between a state-based program under CAA section 111(d) covering existing fossil fuel-fired EGUs and a federal program under CAA section 111(b) covering newly constructed, reconstructed, and modified fossil fuel-fired EGUs. In particular, the EPA requests information on how an existing EGU covered under a CAA section 111(d) state plan might affect the state plan (or an interstate trading program) if the EGU undergoes a reconstruction or modification (as defined under CAA 111(b)). **VI. Statutory and Executive Order Reviews**

Under Executive Order 12866, entitled Regulatory Planning and Review (58 FR 51735, October 4, 1993), this is a “significant regulatory action” because the action raises novel legal or policy issues. Accordingly, the EPA submitted this action to the Office of Management and Budget (OMB) for review under Executive Order 12866 and any changes made in response to OMB recommendations have been documented in the docket for this action. Because this action does not propose or impose any requirements, and instead seeks comments and suggestions for the Agency to consider in possibly developing a subsequent proposed rule, the various statutes and Executive Orders that normally apply to rulemaking do not apply in this case. Should the EPA subsequently determine to pursue a rulemaking, the EPA will address the statues and Executive Orders as applicable to that rulemaking.

Dated: ________________.

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E. Scott Pruitt,
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Sent: 2017-10-31T15:23:02-04:00
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Subject: FW: Comments Requested: SBA Size Standard Methodology White Paper (DUE NOV 13)
Received: 2017-10-31T15:23:43-04:00
2017_Size_Standard_Methodology_final_09252017.docx
Federal Register Notice_Revised Methodology_final_10122017.docx

Hello everyone! Please see attached and below information about SBA’s revised small business size standards. Unfortunately the briefing next week overlaps with our IAWGTT meeting but you may wish to forward to others in your office. If you would like to provide any comments on the white paper or the FRN please do so through your agency’s leg affairs office.

Thanks,
Courtney

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Colleagues - For your review and comments, please find attached SBA's draft revised Size Standard Methodology White Paper and the Federal Register Notice letting the public know the White Paper is

available for comment. Please provide comments on either/both of the documents by **Monday, Nov 13th**.

I have requested a briefing from SBA on **Wednesday, Nov 8th at 9:30am in NEOB room 9258** to go over the changes to the methodology and the rationale behind the changes. If your agency would like to attend, please **RSVP no later than Nov 6th** using the following link -- RSVP Link: https://events.whitehouse.gov/?rid=PF7Q9BRMTR. Since space is limited, agencies can access the discussion via conference line at:

[redacted] (b)(6)

Below is background information provided by SBA:

> In 2007, SBA initiated a comprehensive review of size standards. Subsequently, Congress passed the Small Business Jobs Act in 2010 (Jobs Act) requiring SBA to review, every five years, all size standards and make necessary adjustments to reflect market conditions. SBA recently completed the first five-year review of size standards under the Jobs Act and will start the next five-year review in the near future. As part of the comprehensive size standards review initiated in 2007, SBA formalized a detailed methodology explaining how SBA establishes, reviews and adjust size standards based on industry and Federal contracting factors. In 2009, SBA published a notice in the Federal Register for review of this methodology and accepted comments through September 30, 2015. 78 FR 53940 (Oct. 21, 2009)(Regulations.Gov Docket Number SBA-2009-0008).
>
> The revised methodology addresses the public comments and recent amendments to Small Business Act (the Act) concerning size standards. It also modifies the approach to evaluating the industry structure. SBA plans to use the revised methodology in the next round of size standards review. In response to the comments on the "anchor" standards approach of the previous methodology, and recent amendments to the Act regarding the use of common size standards, SBA is replacing the "anchor" approach with a "quintile" approach.

Regards,
Wendy

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SBA'S SIZE STANDARDS METHODOLOGY

Prepared by:
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Office of Policy, Planning and Liaison
Office of Government Contracting and Business Development
U.S. Small Business Administration

September, 2017

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INTRODUCTION

This document describes the SBA's methodology for establishing, reviewing or adjusting its small business size standards pursuant to the Small Business Act (the Act) and related legislative guidelines. Under the Act (Public Law 85-536, as amended), the SBA's Administrator (the Administrator) has authority to establish small business size standards for Federal government programs. This document provides a detailed description of this revised size standards methodology.

In establishing size standards, the Act and its legislative history highlight three important considerations. First, size standards should vary from industry to industry to account for differences among industries. Second, a small business concern cannot be dominant in its field of operation. Third, the policies of the Agency should assist small businesses as a means of encouraging and strengthening their competitive position in the economy. These three considerations are the basis for the SBA's size standards methodology for establishing, reviewing, or modifying small business size standards.

The SBA's size standards methodology examines the structural characteristics of an industry as a basis to assess industry differences and the overall degree of competitiveness of an industry and of firms within the industry. As described more fully later in this document, industry structure is examined by analyzing four primary factors – average firm size, degree of competition within an industry, start-up costs and entry barriers, and distribution of firms by size. To assess the ability of small businesses to compete for Federal contracting opportunities under the current size standards, as the fifth primary factor, SBA also examines small business share in Federal contracts and entry barriers for small businesses to win Federal contracts. When necessary, SBA also considers other secondary factors as they are relevant to the industries and the interests of small businesses, including technological change, competition among industries, industry growth trends, and impacts on SBA programs.

SBA conducts a statistical analysis of data on the primary factors and secondary factors, if necessary, to establish a size standard for a specific industry. Specifically, SBA ranks each industry within a group of industries with the same measure of size standards (i.e., average annual receipts or number of employees) using the value of each primary factor and assigns a size standard for that factor based on its position in the ranking. The overall size standard for an industry is obtained then by averaging all size standards supported by each primary factor. This represents a major change from the previous methodology where the average characteristics of the industries in the anchor size standards groups (i.e., industries with the $7 million receipts based size standard for industries with receipts based size standards and those with 500-employee size standard for industries with employee based size standards) to evaluate the characteristics of the individual industries.

In addition to reviewing all size standards and adjusting them, as necessary, every five years based on industry and Federal contracting factors in accordance with the Small Business Jobs Act of 2010 (the Jobs Act) (Public Law 111-240, 124 Stat. 2504, Sept. 27, 2010), SBA also periodically adjusts all receipts and other monetary based standards for inflation. Under SBA's regulations (13 CFR 121.102(c)), an adjustment to size standards for inflation will be made at least once every five years. In response to higher than normal rates of inflation, some past inflation adjustments have been made on more frequent intervals.

OVERVIEW OF SBA'S SIZE STANDARDS METHODOLOGY

In keeping with the Act's statutory language and legislative history, SBA's size standards methodology entails examining industry characteristics and the differences among various industries. The remainder of this document describes SBA's approach to analyzing industry structure and a detailed methodology for evaluating and establishing size standards. SBA has always followed the industry structure approach. However, the specifics of SBA's size standards methodology have evolved over the years with the availability of new and richer industry and Federal procurement data and staff research leading to improved analyses of industry structure and Federal market conditions.

In response to the public comments on the "anchor" size standards approach applied in the previous methodology and recent amendments to the Act regarding the use of common size standards (see Section 3(a)(7)), in this revised methodology SBA is replacing the "anchor" approach with a "quintile" approach. Under the "anchor" approach, SBA generally evaluated the characteristics of individual industries relative to the average characteristics of industries with the anchor size standard to other industries to determine whether they should have a higher or a lower size standard than the anchor. In the quintile approach, SBA will rank each industry among all industries with the same measure of size standards using each of the four industry factors. The four industry factors are average firm size, average assets size as proxy for startup costs and entry barriers, industry competition, and distribution of firms by size. Specifically, to be detailed below, the size standard for an industry for a specific factor will be derived based on where the factor of that industry falls relative to other industries sharing the same measure of size standards. If an industry ranks high for a specific factor relative to most other industries, all else remaining the same, a size standard assigned to that industry will be higher for most industries. Conversely, if an industry ranks low for a specific factor relative to most industries in the group, a lower size standard will be assigned to that industry. As the fifth primary factor, SBA also examines small business participation in Federal contracting in terms of the small business share of Federal contracts relative to their share of industry's receipts and the likelihood for small businesses to win Federal contracts. The size standards for each factor are then averaged to obtain the overall size standard for a specific industry in question.

Statutory Authority

Authority for the Administrator to establish small business size standards for Federal Government programs is the Small Business Act (the Act) (Public Law 85-536, as amended). Congress has periodically modified the Act but has not provided specific values for size standards for Federal government purposes, other than for agricultural enterprises. With respect to general directions on how SBA should establish small business size standards for industries, the Act provides the following:

§ 3 (a) (1) For the purposes of this Act, a small-business concern, including but not limited to enterprises that are engaged in the business of production of food and fiber, ranching and raising of livestock, aquaculture, and all other farming and agricultural related industries, shall be deemed to be one which is independently owned and operated and which is not dominant in its field of operation.

(2) ESTABLISHMENT OF SIZE STANDARDS. –

(A) IN GENERAL. – In addition to the criteria specified in paragraph (1), the Administrator may specify detailed definitions or standards by which a business concern may be determined to be a small business concern for the purposes of this Act or any other Act.

(B) ADDITIONAL CRITERIA. – The standards described in paragraph (1) may utilize number of employees, dollar volume of business, net worth, net income, a combination thereof, or other appropriate factors.

(C) REQUIREMENTS. – Unless specifically authorized by statute, no Federal department or agency may prescribe a size standard for categorizing a business concern as a small business concern, unless such proposed size standard --

(i) is proposed after an opportunity for public notice and comment;

(ii) provides for determining --

(I) the size of a manufacturing concern as measured by the manufacturing concern's average employment based upon employment during each of the manufacturing concern's pay periods for the preceding 12 months;

(II) the size of a business concern providing services on the basis of the annual average gross receipts of the business concern over a period of not less than 3 years;

(III) the size of other business concerns on the basis of data over a period of not less than 3 years; or

(IV) other appropriate factors; and

(iii) is approved by the Administrator.

(3) VARIATION BY INDUSTRY AND CONSIDERATION OF OTHER FACTORS.—When establishing or approving any size standard pursuant to paragraph (2), the Administrator shall ensure that the size standard varies from industry to industry to the extent necessary to reflect the differing characteristics of the various industries and consider other factors deemed to be relevant by the Administrator.

(6) PROPOSED RULEMAKING.—In conducting rulemaking to revise, modify or establish size standards pursuant to this section, the Administrator shall consider, and address, and make publicly available as part of the notice of proposed rulemaking and notice of final rule each of the following:

(A) a detailed description of the industry for which the new size standard is proposed;

(B) an analysis of the competitive environment for that industry;

(C) the approach the Administrator used to develop the proposed standard including the source of all data used to develop the proposed rule making; and

(D) the anticipated effect of the proposed rulemaking on the industry, including the number of concerns not currently considered small that would be considered small under the proposed rule making and the number of concerns currently considered small that would be deemed other than small under the proposed rulemaking.

(7) COMMON SIZE STANDARDS.—In carrying out this subsection, the Administrator may establish or approve a single size standard for a grouping of 4-digit North American Industry Classification System codes only if the Administrator makes publicly available, not later than the date on which such size standard is established or approved, a justification demonstrating that such size standard is appropriate for each individual industry classification included in the grouping.

(8) NUMBER OF SIZE STANDARDS.—The Administrator shall not limit the number of size standards established pursuant to paragraph (2), and shall assign the appropriate size standard to each North American Industry Classification System Code.

Paragraph 3(a)(1) of the Act defines a small business concern to be one which is independently owned and operated and not dominant in its field of operation. Under Section 1831 of the National Defense Authorization Act for Fiscal Year 2017 (NDAA 2017) (Public Law 114-328, December 23, 2016), Congress amended paragraph 3(a)(1) of the Act authorizing the Administrator to establish size standards for agricultural enterprises in the same manner as for other industries. The amendment also subjects size standards for agricultural enterprises to the rolling review procedures established under section 1344(a) of the Small Business Jobs Act of 2010. Historically, the size standards for most agricultural industries were established by statute.

Paragraphs 3(a)(2)(A) and 3(a)(2)(B) give the Administrator the flexibility to establish size standards using a broad range of criteria, depending on what the Administrator determines will serve small businesses the best. Paragraph 3(a)(2)(C) refers to the use and establishment of size standards by other Federal agencies and paragraph 3(a)(3) provides that the Administrator shall vary the size standard from industry to industry to reflect differing characteristics of the various industries and consider other relevant factors when establishing a size standard.

While the requirements for conducting rulemaking to establish, revise or modify size standards are stated in paragraph 3(a)(6), the requirements for establishing a common size standard by grouping industries at the 4-digit North American Industry Classification System (NAICS) level are provided in paragraph 3(a)(7). Finally, paragraph 3(a)(8) directs the Administrator not to limit the number of size standards and assign the appropriate size standard for each NAICS industry. In response to the last two paragraphs that were added after the publication of the previous size standards methodology, in this updated methodology SBA has abandoned the use of the anchor size standard approach and fixed number or “bands” of size standards.

Along with the above broad statutory requirements, the Act also directs the Agency to encourage competition and to insure that a fair proportion of total Federal purchases, contracts, and property sales be placed with small business enterprises (Section 2(a)). Congress went on to state that "the preservation and expansion of such competition is basic not only to the economic well-being but to the security of this Nation." 15 U.S.C.§ 631(a).

Legislative History

The above statutory language provides the Administrator with broad discretion in establishing, reviewing, or revising size standards. Reading the legislative history of the Act provides a better understanding of Congress' intent in the Act. The requirement that a small business concern be "independently owned and operated" requires SBA to define the size of a firm together with its affiliates when calculating its size.[1] Therefore, SBA must consider not only the size of a firm but also the size of all of its affiliates (both domestic and foreign) when establishing, reviewing, or revising size standards and when determining its small business eligibility for Federal government programs. In addition, Congress did not intend the phrase "is not dominant in its field of operations" to exclude firms that might dominate a geographic area. Rather, Congress intended to exclude firms that dominate an entire industry, nationally.[2] Congress also recognized that an extremely high percentage of business firms could properly be classified as small.[3]

The Banking and Currency Committee recognized the "impossibility of attempting to write into law a rigid definition of small business."[4] Therefore, Section 3 of the bill defines a small business concern in a flexible and realistic manner. The Committee did this "because it has become universally recognized that it is utterly impossible to define small business rigidly in terms of number of employees, amount of capitalization, or dollar volume of business."

In 1957, the House Committee on Banking and Currency addressed how to characterize a small business and stated that "no single definition may be expected to meet all requirements." Recognition of varying situations motivated the Committee in drafting the present Small Business Act to depart from rigid standards and leave the definition of small business to administrative determination.[5] That same report explains that the origins of the present statutory requirement that the Agency vary the size standards from industry to industry where number of employees is used as

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[1] See Hearings on H.R. 4090 and H.R. 5141 before the Committee on Banking and Currency of the U.S. House of Representatives, 83rd Congress, 1st Session (1953), page 17.

[2] See Hearings on S. 982. *et al*. before the Committee on Banking and Currency of the U.S. Senate, 83rd Congress, 1st Session (1953), page 56.

[3] See comments of Representative Seely-Brown, Congressional Record-House, June 5. 1953, page 6141. Representative Seely-Brown observed that more than 95 percent of business establishments could be classified as small and Representative Springer at page 6155 of the same Congressional Record observed that 95.2 percent of the businesses employed less than 20 people, so that on the basis of employment small business would be truly small in size.

[4] See House Report No. 494, 83rd Congress, 1st Session (1953).

[5] See Senate Report No. 555, 85th Congress, 1st Session, page 6.

the criteria was the result of the Agency's then existing flat 500-employee rule for all government contracts.

Regulatory History

Current small business size standards evolved from a limited number of general size standards for broad industry groups or sectors to a larger number of specific size standards based on individual industries. This transition was recognition that different industries had different characteristics, and thus warranted appropriate industry specific size standards. Many of today's size standards continue at levels established right after the SBA's inception, except that receipts based size standards have been increased for inflation over the years.

Over the years, SBA has adopted a broad range of size standards – manufacturing industry standards ranged from 250 employees to 1,500 employees; other industry size standards ranged from $0.10 million to $38.5 million in average annual receipts. SBA establishes its size standards for industries using the latest NAICS industry definitions, developed by the Office of Management and Budget (OMB) in collaboration with U.S. Census Bureau, other U.S. Federal Statistical Agencies, and Statistical Agencies of Canada and Mexico. NAICS replaced the Standard Industrial Classification (SIC) system for SBA's size standards on January 1, 1997. SBA adopted NAICS as the basis for its table of size standards, effective October 1, 2000 (65 FR 30836 (May 15, 2000)). OMB modifies or updates NAICS every five years and SBA adopts the NAICS updates for its table of size standards, effective October 1 of the same year. SBA has opted to use October 1 because that is the start of the Federal government's fiscal year.

The 500-employee size standard for Federal contracting predates SBA; it was used by the Reconstruction Finance Corporation and the earlier Small War Plants Corporation, which was a World War II Government contracting agency channeling Federal contracts to small manufacturers. In 1957, the House Committee on Banking and Currency observed that "the standard of 500 or less employees originated in World War II with several variations. For the want of a better definition, the 500 rule generally gained acceptance in the Government, although in many instances there was considerable reluctance by many Government officials and members of Congress to accept such a rigid formula." (*See* Senate Report No. 555, 85th Congress, 1st Session, page 6.)

SBA adopted 500 emp1oyees as the size standard for manufacturing industries at its 1953 inception; it has remained a standard for many industries until today and had long been considered the "anchor" size standard for employee based size standards. In 1959, SBA's size regulations distinguished between manufacturing and financial industries. Specifically, the Agency adopted 250-employee, 500-employee, and 1,000-employee size standard for its financial assistance programs, but maintained the 500-employee size standard for Federal contracting programs.

Generally, the Agency has used annual receipts as the measure of size standards for nonmanufacturing industries. Soon after its inception, SBA created size standards for nonmanufacturing based on annual receipts rather than employees. In 1954, SBA established a $1 million in average annual receipts as the size standard for nonmanufacturing industries. Receipts based size standards were established subsequently for other industries. They varied between $0.30 million and $1 million for retail and services industries, between $2 million and $5 million for wholesale industries, and $5 million for construction industries. SBA has periodically increased

all receipts based size standards for inflation. With the inflation adjustment, the most common receipts based size standard of $1 million has increased to $7.5 million today. The $1 million level and its inflation-adjusted equivalent had long been considered the "anchor" size standard for industries with receipts based size standards.

By 1963, SBA receipts based size standards were as follows: $1 million for retail trade industries; $1 million for services industries; $5 million for wholesale industries; and $7.5 million for construction industries. SBA continued using two sets of size standards for manufacturing industries – 250 employees to 1,000 employees for SBA financial programs, but basically 500 employees for Federal contracting programs.

From 1963 to 1975, many manufacturing size standards were increased from 500 employees to 750 or 1,000 employees. Similarly, some services industries, such as engineering and janitorial services were broken into separate industries, with size standards of $5 million and $3 million, respectively.

In 1975, SBA adopted a general increase to its monetary based size standards for inflation (40 FR 32824 (August 5, 1975)). As a result, the new size standards were $2 million for retail trade and services industries, $12 million for general construction, and $5 million for special trade construction. Employee based standards remained unchanged.

After a series of public notices in the *Federal Register* from 1980 to 1983, the Agency adopted a detailed list of size standards for industries as defined under the SIC system. Generally speaking, the size standards framework the Agency followed until the recently completed comprehensive size standards review was put in place in 1984.

In 1984, to simplify procurement procedures, SBA adopted a single size standard of 500 employees for all Wholesale Trade industries, for both procurement and SBA programs (49 FR 5024 (February 9, 1984)). Before that, the Wholesale Trade industries had a 500-employee size standard for Federal procurement and three levels of receipts based standards ($9.5 million, $14.5 million and $22 million) for SBA's financial programs. In 1986, SBA amended its standards for the Wholesale Trade industries from 500 employees to 100 employees for all SBA programs (51 FR 25189 (July 11, 1986)), while it retained 500-employee size standard for Federal procurement.

In 1992, SBA proposed, along with an inflation adjustment, a reduction in the number of size standard levels from more than forty different levels to nine receipts based size standards and five employee based size standards (57 FR 62515 (December 31, 1992)). SBA withdrew the proposed rule on February 19, 1993 (58 FR 9131) and re-published on September 2, 1993 (58 FR 46573). Although public comments overwhelmingly accepted the fixed size standards approach, the proposed levels seemed arbitrary and produced large variations in changes to standards. SBA believed it could not justify such large variations, and therefore, limited the final rule to adjusting the then existing receipts based size standards for inflation (59 FR 16513 (April 7, 1994)).

In March 2004, SBA proposed to simplify and restructure size standards by establishing all size standards based on number of employees (69 FR 13130 (March 19, 2004)). For a number of

industries, however, an employee based size standard could result in businesses with very high receipts but few employees to qualify as small. There were other skewed outcomes as well, and SBA, therefore, also proposed a maximum receipts size standard along with an employee size standard for certain industries. Public comments showed that for some industries the proposed employee based standards were either too low or did not serve as a suitable measure of business size. Rather than issuing a revised proposed rule with adjusted size standards, SBA decided to seek additional input from the public.

Accordingly, in December 2004, the Agency issued an Advance Notice of Proposed Rulemaking (ANPRM) (69 FR 70197 (December 3, 2004)). It sought comments on 10 specific issues that the public had raised in response to the March 2004 proposed rule. SBA did not make further proposals, but only sought public comment on whether and how it should consider the following: 1) Approaches to simplification of size standards; 2) Calculation of number of employees; 3) Use of receipts based size standards; 4) Designation of size standards for Federal procurements; 5) Establishment of size standards solely for Federal procurement; 6) Establishment of tiered size standards; 7) Simplification of small business status and affiliation with other businesses; 8) Joint ventures and small business eligibility; 9) Grandfathering of currently eligible small businesses; and 10) Impact of SBA size standards on the regulations of other Federal agencies. SBA received several thousand comments on these issues, but no consensus.

In 2007, SBA began a comprehensive review of all size standards to determine whether the existing size standards were consistent with current data, and to revise them, when necessary. In addition, on September 27, 2010, the President of the United States signed the Small Business Jobs Act of 2010 (Jobs Act), 111 Pub. L. 240, 124 Stat. 2504, Sep. 27, 2010. The Jobs Act directs SBA to conduct, at least every five years, a detailed review of all size standards (except those for agricultural enterprises) and to make appropriate adjustments to reflect market conditions. SBA recently completed the first five-year comprehensive size standards review and will begin the next five-year review in the near future. Section 1831 of NDAA 2017 requires SBA to include agricultural size standards in the five-year rolling review procedures established under the Jobs Act.

Currently, the most prevalent size standards are $7.5 million in annual receipts for Retail Trade and Services, $35.5 million for General Construction, $15 million for Special Trade Construction, 100 employees for Wholesale Trade for all Federal programs except for Federal procurement where it is 500 employees under the non-manufacturer rule, and 500 employees for Manufacturing industries. Monetary based size standards range from $0.75 million in annual receipts for most Agricultural enterprises (which were set by statute until the enactment of NDAA 2017) to $38.5 million in annual receipts for Facility Support Services. Similarly, employee based standards range from 100 employees for Heating Oil Dealers to 1,500 employees for some Manufacturing and Telecommunications industries. With a very few exceptions, uniform size standards are now in place for all SBA's programs.

Selection of Size Measure

SBA has primarily used two measures of business size for its size standards– receipts and number of employees. SBA generally prefers receipts as a measure of business size because it measures the value of total output of a business concern and can be easily verified using business tax returns and financial records. Historically, the number of employees has been primarily used for

manufacturing industries and average annual receipts for services industries. The 500-employee manufacturing size standard had been utilized by the Small War Plants Corporation, the Small Defense Plants Administration, and the Reconstruction Finance Agency prior to SBA's inception. Other size measures are applied to a few specific industries.

The choice of a size measure for an industry depends on which measure best represents the magnitude of operations of a business concern. That is, the measure should indicate the level of real business activity generated by firms in the industry. Table 1 below summarizes a list of several industry factors SBA considers when selecting the number of employees or receipts as an appropriate measure for size standards.

For a limited number of industries or programs, SBA has established size measures based on other business characteristics, including average assets for certain financial institutions, total refining capacity for petroleum refiners, and tangible net worth and net income for the Small Business Investment Companies, 7(a) and 504 financial assistance programs. These are summarized in Table 2.

SBA decided to apply the net worth and net income measures to its SBIC program because investment companies evaluate businesses using these measures to decide whether or not to make an investment in them. The net worth and net income based size standard also applies for SBA's 7(a) and community development companies (CDC) loan as an alternative to industry based size standards.

Table 1

Industry Factors Supporting Employee vs. Receipts Based Size Measure

Industry factor	No. of employees	Receipts	Reason
Highly capital intensive	✓		Employment levels vary with level of production while value of output substantially derived from fixed assets.
Low operational costs relative to receipts	✓		Large receipts amounts generated with low labor inputs.
Variation of firms within industry by stage of production or degree of vertical integration	✓		Firm's value added contribution to final value varies depending on structure of firm. Employment is more strongly correlated to value added than receipts.
Horizontally structured firms	✓		Varying receipts to employee relationships among firms.
Highly labor intensive		✓	Value of output varies with employment level and more easily verified.
Ease of factor substitution		✓	Same value of output can be achieved by varying levels of labor and capital inputs.
Presence of subcontracting		✓	Same value of output is achieved with differing levels of outsourcing.

High proportion of part-time or seasonal employment		✓	Same level of output is achieved with differing employment practices.
Operation in multiple industries		✓	Receipts is a more homogenous measure than employment.

Table 2
Production Capacity and Financial Size Measures

Category	Measure	Comment
Production capacity	Barrels/day of petroleum refining	Applied to petroleum refiners in combination with number of employees
Financial measure	Total assets	Applied to most banking and other depository industries.
	Net worth Net income	Applied to the SBIC, 7(a) and 504/CDC programs as an alternate size standard to the industry size standards.

Assumptions

Several assumptions underpin the structure of SBA's small business size standards, which in turn drive the methodological framework the Agency applies in size standards analysis. These assumptions are as follows:

1. SBA establishes size standard by industry category. As stated in the Small Business Act, size standards shall differ to reflect industry differences. Based on the analysis of industry data and public feedback, SBA has determined that a single, one-size-fits-all size standard is inappropriate to define the small business segment of each and every industry. For purposes of size standards, SBA utilizes the latest NAICS of the United States as a basis for industry definitions. Except for a few exceptions where a size standard may be established for a specific activity within in an industry, size standards are primarily defined at the 6-digit NAICS industry level.

2. An industry's size standard is established at the national level. Similarly, the determination of "not dominant in its field of operation" is also made at the national level. Data limitations preclude an extensive analysis of businesses within specific industries on a geographical basis. In addition, geographically based size standards may inappropriately influence decisions on business location.

3. A single set of size standards applies to most SBA's programs. For some programs, a "program-based" or an alternative size standard may be established. However, in most of these cases, the size standard is related to the size standard for the industry of most program participants, such as the Small Business Innovation Research size standard.

4. An industry's size standard will be determined from the analysis of industry and Federal contracting factors and will be bounded by a minimum and a maximum size standard. For this revised methodology, however, there will not be a predetermined range of fixed size standard levels as in the previous methodology. The starting point of the analysis will be the percentile distribution of each factor considered in the evaluation. A size standard above or below the current size standard will be selected within a range of predetermined minimum and maximum size standards, depending on the results of the analyses of relevant industry and Federal contracting data available. SBA's size standards will generally reflect sizes higher than the typical firm size at the entry level in order to include businesses that are competitively disadvantaged due to their size or to include businesses that are small relative to the characteristics of all businesses within an industry. Size standards will also reflect business capabilities to be able to compete for and perform Federal contracts within an industry.

5. With a few exceptions, each size standard shall have only one measure of size. That is, almost all industries will have either a number of employees or receipts based size standard, not both. In very limited cases an additional measure of size related to production or capacity may be included with an employee or receipts measure. For example, the size standard for the petroleum industry includes a combination of the refining capacity and the number of employees.

6. A business is defined on an enterprise basis rather than at the establishment level or any other similar legally incorporated entity. Accordingly, the size of a business concern includes all establishments, subsidiaries and affiliates under its control (whether controlled through ownership or other relationships). Similarly, the size of a business concern owned or controlled by another concern includes the size of its parent company and all of its subsidiaries and affiliates.

7. This methodology explains how SBA generally establishes, reviews, or modifies small business size standards and what data sources and factors it evaluates in its size standards analysis. It serves as a general analytical basis in establishing, reviewing, or revising size standards. However, such considerations as the President's, Administrator's, or Congressional priorities, programs and policy directives may require SBA to deviate from this framework when establishing or adjusting size standards. Additionally, the presence of unique characteristics or market conditions in specific industries may also warrant an adjustment to the methodology laid out in this document when reviewing or modifying their size standards.

Establishing Comparison Industry Groups

The goal of SBA's size standards review is to determine whether its existing small business size standards reflect the current industry structure and Federal market conditions and revise them, when the latest available data suggest that revisions are warranted. In the past, SBA compared the characteristics of each industry with the average characteristics of a group of industries associated with the "anchor" size standard. For example, in the recently completed comprehensive size standards review, the $7 million (now $7.5 million due to the inflation adjustment in 2014) was considered the "anchor" for receipts based size standards and 500 employees was the "anchor" for

employee based size standards. If the characteristics of a specific industry under review were similar to the average characteristics of industries in the anchor group, SBA generally adopted the anchor size standard for that industry. If the specific industry's characteristics were significantly higher or lower than those for the anchor group, SBA assigned a size standard that was higher or lower than the anchor.

To determine a size standard above or below the anchor size standard, SBA evaluated the characteristics of a second comparison group. For industries with receipts based standards, the second comparison group consisted of industries with size standards between $23 million and $35.5 million, with the weighted average size standard for the group equaling $29 million. For manufacturing industries and other industries with employee based size standards (except for Wholesale Trade and Retail Trade), the second comparison group included industries with a size standard of 1,000 employees or 1,500 employees, with the weight average size standard of 1,323 employees. Using the anchor size standard and average size standard for the second comparison group, SBA computed a size standard for an industry's characteristic (factor) based on the industry's position for that factor relative to the average values of the same factor for industries in the anchor and second comparison groups.

In response to the comments, section 3(a)(7) of the Act that limits the SBA's ability to create common size standards by grouping industries below the 4-digit NAICS level, and its own review of the methodology, in this revised methodology, SBA is replacing the "anchor" approach with the "percentile" approach as a basis of deriving a size standard for each factor for each industry.

In the past, including the recent review of size standards, the anchor size standards applied to a large number of industries, making them a good reference point for evaluating size standards for individual industries. For example, at the start of the recent review of size standards, the $7 million anchor standard was the size standard for more than 70 percent of industries that had receipts based size standards. Similarly, a similar proportion of industries with employee based size standards had the 500-employee anchor standard. However, when the characteristics of those industries were evaluated individually, for a large majority of them the results yielded a size standard different from the applicable anchor. Consequently, now just 24 percent industries with receipts based size standards and 22 percent of those with employee based size standards have the anchor size standards. The "anchor" approach would entail grouping industries from different NAICS sectors, thereby making it inconsistent with section 3(a)(7) of the Act.

Under the percentile approach, for each factor, an industry is ranked and compared with the 20^{th} percentile and 80^{th} percentile values of that factor among the industries sharing the same measure of size standards (i.e., receipts or employees). Combining that result with the 20^{th} and 80^{th} percentile values of size standards among the industries with the same measure of size standards, SBA computes a size standard supported by each industry factor for each industry. In the previous methodology, comparison industry groups were predetermined independent of the data, while in the revised methodology they are established using the actual data. This procedure is illustrated in details in the subsequent sections of this document.

Primary Factors

The primary factors that SBA evaluates in analyzing the economic characteristics defining the structure of an industry include average firm size, start-up costs and entry barriers, industry

competition, and distribution of firms by size (13 CFR § 121.102(a)). Besides industry structure, SBA also examines the impact of an existing size standard as well as the potential impact of a size standard revision on small business participation in Federal contracting as an additional primary evaluation factor when establishing or reviewing the size standards. SBA generally considers these five factors – average firm size, start-up costs and entry barriers, industry competition, size distribution of firms, and small business participation in Federal contracting – to be the most important elements in determining an industry's size standard.

Secondary Factors

Besides the primary factors listed above, SBA also considers, if necessary, a number of other factors that are relevant when deciding a size standard for a particular industry. These factors include, but are not limited to, technological changes, industry growth trends, SBA's financial assistance and other program factors, the presence of competing or similar products among industries, and unique activity within an industry.

Public Comments

Public comments on proposed size standard rules provide additional important information. These comments can supplement SBA's analysis of industry structure and Federal market conditions or the data it used, thereby enabling it to consider other relevant information, where appropriate, in the final decision on a size standard. SBA thoroughly reviews all public comments before making final decisions on proposed changes to size standards in the proposed rule.

Subsequent sections provide a detailed description of the analysis of these factors. Figure 1, below, provides an overview of SBA's size standards methodology.

PRIMARY FACTORS DESCRIBING INDUSTRY STRUCTURE

Average Firm Size

SBA computes two measures of average firm size: simple average firm size and weighted average firm size. For industries with receipts based size standards, SBA calculates the simple average firm size in terms of receipts as follows:[6]

$$Simple\ Average\ firm\ size\ \ (receipts) = \frac{Total\ receipts\ in\ an\ industry}{Total\ number\ of\ \ firms\ in\ that\ industry}$$

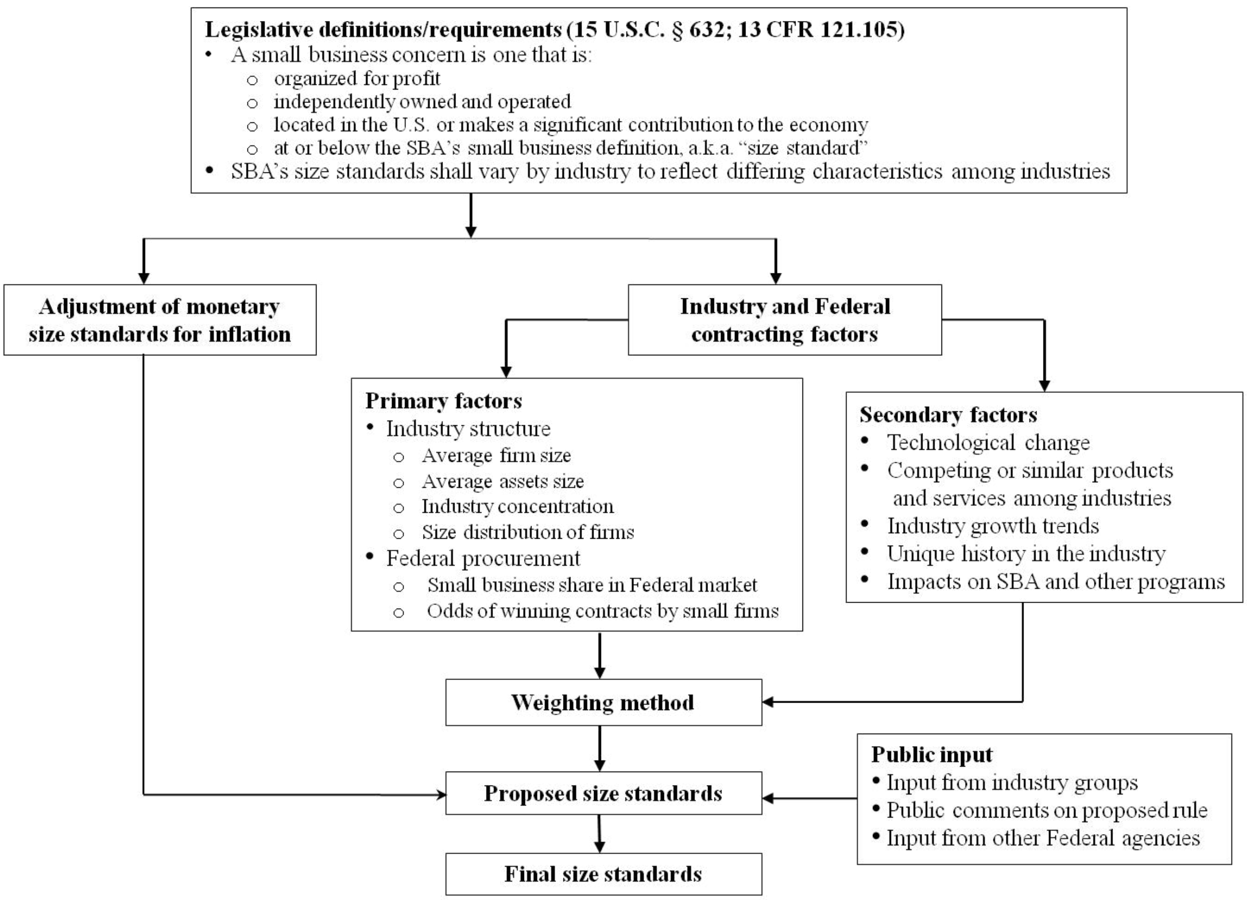
Similarly, for industries with employee based size standards, the simple average firm size is expressed in terms of the number of employees as follows:[7]

$$Simple\ Average\ firm\ size\ \ (employees) = \frac{Total\ number\ of\ employees\ in\ an\ industry}{Total\ number\ of\ \ firms\ in\ that\ industry}$$

[6] For details on SBA's calculations of annual receipts, *see* 13 CFR Part 121.104.

[7] For details on SBA's calculations of number of employees, *see* 13 CFR Part 121.106.

Figure 1. Overview of SBA's Size Standard Methodology



One limitation of simple average firm size is that it weighs all firms within an industry equally regardless of their size. To overcome this, SBA also calculates the weighted average firm size, which gives more weights to larger firms. For industries with receipts based size standards, SBA calculates the weighted average firm size in terms of receipts as follows:

$$Weighted\ average\ firm\ size\ (receipts)$$
$$= \sum_{i=1}^{m} Receipts\ of\ firm\ i\ in\ an\ industry\ \ x \left(\frac{Receipts\ of\ firm\ in\ the\ industry}{Total\ receipts\ in\ the\ industry}\right)$$
$$= \sum_{i=1}^{m} (Receipts\ of\ firm\ i\ in\ an\ idnsutry)\ x(Firm\ i's\ receipts\ share\ of\ in\ the\ industry)$$

Similarly, for industries with employee based size standards, the weighted average firm size is expressed in terms of the number of employees as follows:

$$Weighted\ average\ firm\ size\ (employees)$$
$$= \sum_{i=1}^{m} Employees\ of\ firm\ i\ in\ an\ industry\ x \left(\frac{Employees\ of\ firm\ in\ the\ industry}{Total\ employees\ in\ the\ industry}\right)$$
$$= \sum_{i=1}^{m} Employees\ of\ firm\ i\ in\ an\ industyr\ x(Firm\ i's\ employee\ share\ in\ the\ industry)$$

SBA does not have access to data on individual firms to compute on its own the weighted average firm size using these formulas. SBA requested the U.S. Census Bureau to provide the estimates of the weighted average firm size as part of the 2012 Economic Census special tabulations.

Average firm size is likely to be positively related to minimal efficient (optimal) firm size. The minimal efficient firm size refers to the level of output where firms in an industry are able to minimize their average cost of production and become competitive. Thus, conceptually, an industry's size standard should be set such that firms that have not achieved a minimal efficient firm size to remain competitive will be considered small and thus be eligible for SBA assistance, while firms that are fully competitive would exceed the size standard and thus be considered ineligible. Everything remaining the same, the higher the minimal efficient firm size for an industry, the higher should be its size standard. In general, industries with high minimal efficient size tend to be dominated by larger firms and, thus, their average firm size (especially weighted average) tends to be large.[8] Given the lack of data on minimal efficient firm size by industry, SBA uses the average firm size as the proxy of minimal efficient firm size.

Because firms often compete with each other across industry lines, it is reasonable to compare the average firm size of an industry relative to the average firm size of other industries

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[8] For discussion on the minimal firm size, *see* Sherer and Ross (1990).

and then to compute the size standard for the industry depending upon that comparison. If the average firm size of an industry is higher than the average firm size for most other industries, this would generally support a size standard higher than the size standards for other industries. Conversely, if the industry's average firm size is lower than that of most other industries, it would provide a basis to assign a lower size standard as compared to size standards for most others industries.

Start-up Costs and Entry Barriers

Start-up costs and entry barriers reflect, among other things, the amount of capital requirements for physical plant and production equipment new firms must have to enter an industry and become competitive with existing firms.[9] If firms entering an industry under review have greater capital requirements than firms do in most other industries all factors remaining the same, this would be a basis for a higher size standard. Conversely, if the industry has smaller capital needs compared to most other industries, a lower size standard would be considered appropriate.

Given the lack of data on actual start-up costs and other measures of entry barriers (such as degree of product differentiation, advertising expenses, economies of scale, government policy, *etc*.), SBA uses average assets size as a proxy for the levels of capital needs for new businesses entering an industry.[10] An industry with a significantly higher average assets size than most other industries in the group is likely to have higher start-up costs, which in turn would support a size standard higher than that for most other industries.

SBA continues to explore other approaches and various data sources (including sales to assets from Risk Management Association and assets data from the Internal Revenue Service) in assessing start-up costs which may lead to a more robust assessment of this factor in deriving a size standard in the future. As with any change to the methodology, SBA will explicitly explain why and how it has incorporated a new approach into the methodology. SBA welcomes comment on alternative approaches to and/or data sources for measuring start-up costs and entry barriers when establishing or evaluating industry size standards.

Industry Competition

A fundamental purpose of small business size standards is to support SBA's mission and programs to promote market competition. A prevailing method of analyzing industry competition is the measurement of concentration or market power to determine the extent to which a particular industry is dominated by a few large firms.

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[9] For detailed discussion of these factors, see Porter (1998).

[10] Several studies have also used average assets size as a proxy for levels of capital requirements in analyzing industry structure, especially entry barriers (*e.g., see* Bain, 1956; Comanor and Wilson, 1967; and Guth, 1971). Comanor and Wilson (1967) recognize that this measure is likely to understate capital requirements. The book value of total assets will normally be less than their replacement cost, as a result of inflation in preceding years. This measure also fails to account for intangible assets such as information and knowledge advantage of incumbent firms. In the past, SBA used average non-payroll costs as a proxy for capital needs.

To determine the degree of concentration in an industry, SBA evaluates various standard measures of industry concentration, including the 4-firm concentration ratio, Gini coefficient, and the Herfindahl-Hirshman index (HHI).[11]

The oldest and most commonly used measure of industry concentration is the *K*-firm concentration ratio, defined as the cumulative share of total industry receipts (or other dimension of size) obtained by the leading (largest) *K* firms within an industry. More formally, the *K*-firm concentration ratio (CRK) is defined as (Curry and George, 1983):

$$CRK = \sum_{i=1}^{K} s_i$$

where $s_i\ (market\ share) = \frac{Total\ receipts\ of\ firm\ i\ in\ an\ industry}{Industry's\ total\ receipts}$

i = 1, 2,…, K largest firms in the industry such that $s_1 > s_2 > \ldots > s_K$.

SBA has generally used the 4-firm concentration ratio or the cumulative share of total industry receipts of the four biggest firms as a measure of industry competition when establishing or reviewing its size standards, including the recently completed comprehensive size standards review. The 4-firm concentration ratio is the most commonly used concentration measure for judging the degree of industry competition (Lipczynski, Wilson and Goddard, 2005). Using the notations from the above formula, the 4-firm concentration ratio (CR4) is defined as:

$$CR4 = \sum_{i=1}^{4} s_i \text{, where } s_1 > s_2 > s_3 > s_4.$$

In addition to CR4, in preparing this revised methodology, SBA also evaluated the appropriateness of the 8-firm concentration ratio (CR8) and HHI as additional or alternative measures of industry concentration.[12] CR8 is the same concept as CR4, except that it represents the cumulative market share of the eight largest firms, instead of four. CR8 can provide additional information on the difference in concentration across industries or change in an industry's concentration over time, even if CR4 shows no difference or no change. The CR4, CR8, and HHI estimates for individual industries based on the 2012 Economic Census tabulation

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[11] These measures are widely applied in measuring industry concentration. For example, *see* Pulaz and Kume (2013).

[12] $CR8 = \sum_{i=1}^{8} s_i$, where $s_1 > s_2 > \ldots > s_8$. The Herfindahl-Hirshman index (HHI) is computed as follows (Curry and George, 1983):

$$HHI = \sum_{i=1}^{n} s_i^2$$

where $s_i\ (market\ share\ \%) = \frac{Total\ receipts\ of\ firm\ i\ in\ an\ industry}{Industry's\ total\ receipts} \times 100$

and i = 1, 2, 3, …, n denotes the total number of firms in an industry.

are found to be strongly correlated to each other and yielded similar conclusions regarding industry concentration. Therefore, SBA has decided to continue applying the 4-firm concentration ratio as a measure of market competition.

Using the 4-firm concentration ratio SBA compares the degree of concentration within an industry to the degree of concentration of the other industries with the same measure of size standards. If a significantly higher share of economic activity within an industry is concentrated among the four largest firms compared to most other industries, all else being equal, SBA would set a size standard that is relatively higher than for most other industries. Conversely, if the market share of the four largest firms in an industry is appreciably lower than the similar share for most other industries, the industry will be assigned a size standard that is lower than those for most other industries.

In the past, SBA generally did not consider the 4-firm concentration ratio as an important factor in size standards when its value was below 40%.[13] If an industry's 4-firm ratio was 40% or more, SBA used the average size of the four largest firms as a primary factor in determining a size standard for that industry.[14] In response to the comment as well as based on its own evaluation of industry factors, in this revised methodology, SBA is proposing to apply all values of the 4-firm ratios directly in the analysis, as opposed to using only 40% and above. The 40% rule generally applies only to about one-third of industries for which this information is available. According to the 2012 Economic Census data, about two-thirds of industries had a 4-firm ratio of less than 40%. For the same reason, SBA is also proposing to drop the average firm size of the four largest firms. Moreover, the four-firm average size is found to be highly correlated with the weighted average firm size.

Size Distribution of Firms and Gini Coefficient

SBA examines the shares of industry total receipts accounted for by firms of different receipts and employment sizes in an industry. This is an additional factor SBA considers in assessing competition within an industry besides CR4.[15] If the preponderance of an industry's economic activity is attributable to smaller firms, this generally indicates that small businesses are competitive in that industry and would support adopting a smaller size standard. A higher size standard higher would be supported for an industry in which the distribution of firms indicates that most of the economic activity is concentrated among the larger firms.

[13] According to Martin (2002), the CR4 value of 40% is used as the cut-off point, meaning that a 40% or higher value would imply a concentrated (oligopolistic) industry and less than 40% would imply a competitive industry. Shepherd (1991) also notes that a market share over 40% indicates market dominance.

[14] Average size of four largest firms (*AVG4*) is computed as follows:

$$AVG4 = \frac{Total\ receipts\ (employees)\ of\ the\ biggest\ four\ firms\ in\ an\ industry}{4}$$

[15] The 4-firm concentration ratio suffers from a limitation that it only focuses on the cumulative share of the four largest firms in the industry and it does not account for differences in concentration among the four largest firms and remaining firms. The distribution of firms by size addresses that limitation of CR4. The Gini coefficient has been traditionally used in measuring income distribution, but recently it is also being used for analyzing industry structure (*see* Lu *(2016))*.

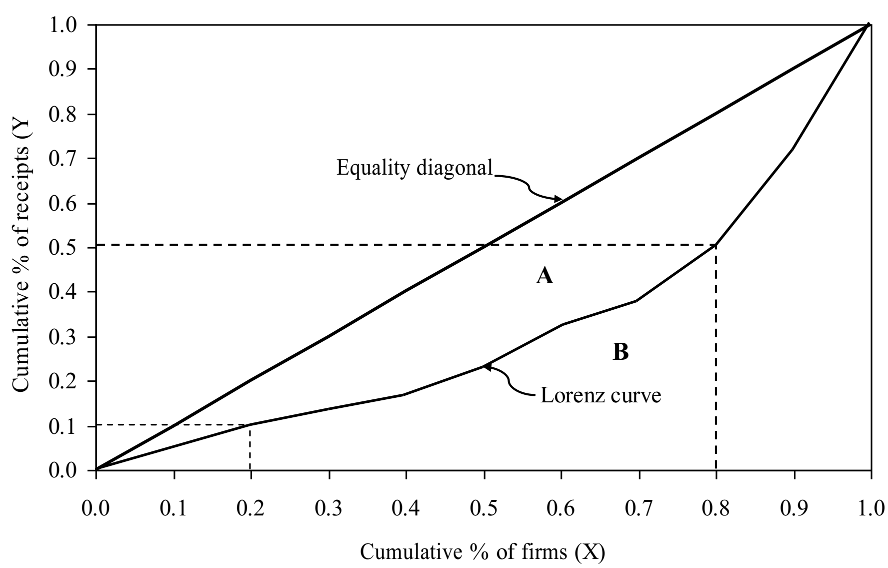
Concentration among firms, like concentration of income among households, is a measure of inequality of distribution. The usual practice in measuring inequality of distribution is to arrange the firms (or groups of firms) in order of increasing size and express inequality in terms of percentages: for example "*X*" percentage of firms hold "*Y*" percentage of total receipts (or other dimensions of size such as employees or assets) in an industry. This comparison is often made in terms of the Lorenz curve, where cumulative percentages of units (firms) are shown in horizontal axis and percentages of receipts (or other measures of size) are in the vertical axis (*see* Figure 2). In the figure, 80% of firms hold 50% of total receipts in an industry. A diagonal line connecting the X-Y coordinates (0, 0) and (1, 1) represents perfect equality, since every point on the line the "*X*" and "*Y*" percentages are equal.

The ratio of the area between the diagonal and the Lorenz curve (area A) to the whole area below the diagonal (area A plus area B) serves as a coefficient of inequality, known as the Gini coefficient. If receipts are distributed perfectly equally among all the firms in the industry, then the Lorenz curve and the line of perfect equality coincide (i.e., area A equals zero), and hence the Gini coefficient becomes zero. If all the receipts are attributed to one firm, the Lorenz curve would pass through the points (0, 0), (1, 0) and (1, 1), and areas A and B would be identical, producing the value of Gini coefficient equal to one. Accordingly, the Gini coefficient values vary between zero and one, with zero implying perfect equality and one indicating perfect inequality.

There are several statistical formulas for calculating the Gini coefficient. The following basic definition, in terms of Figure 2, provides a starting point for these formulas.

$$Gini\ coefficient\ (G) = \frac{Area\ A}{(Area\ A + Area\ B)} = \frac{Area\ A}{0.5} = 2 \cdot Area\ A = 1 - 2 \cdot Area\ B$$

Figure 2. Lorenz Curve of Distribution of Firms by Size



Note that since total area of the box in Figure 1 is 1.0, area below the diagonal (A+B) is half of that or 0.5. One common approach to estimating G is to estimate the value for "2 Area B" in the formula and subtract it from 1. For this revised methodology, SBA estimates the Gini coefficient from the following formula that uses the distribution of deciles for all firms within an industry ranked by receipt size of each firm.[16]

$$G_i = \left(\sum_{\mathrm{k}=1}^{m=10} x_k * y_{k+1}\right) - \left(\sum_{\mathrm{k}=1}^{m=10} x_{k+1} * y_k\right)$$

where

G_i = Gini Coefficient for industry i

x_k = Cumulative percentage of firms at the kth decile for industry i

y_i = Cumulative percentage of receipts at the kth decile the for industry i

m = number of class intervals (here m = 10 because the intervals are in deciles)

Given the data confidentiality issue, SBA does not have access to information on individual firms to compute the Gini coefficient on its own. Therefore, for the 2012 Economic Census special tabulation, SBA requested the U.S. Census Bureau to provide the estimates of the Gini Coefficient using the above formula.

SBA compares the degree of inequality of distribution for an industry under review with other industries with the same type of size standards. If an industry shows a higher degree of inequality of distribution (hence a higher Gini coefficient) compared to most other industries in the group this would, all else being equal, warrant a size standard that is higher than the size standards assigned to most other industries. Conversely, an industry with lower degree of inequality (*i.e.*, a lower Gini coefficient) than most others will be assigned a lower size standard relative to others.[17]

FEDERAL CONTRACTING FACTORS

Besides industry factors described above, SBA also considers Federal contracting as one of the primary factors when establishing or reviewing size standards. The Small Business Act requires Federal government to ensure that small businesses receive a "fair share" of Federal contracts. The legislative history also discusses the importance of size standards in Federal contracting. In this revised methodology, SBA has expanded its approach to incorporating the Federal contracting factor in the size standards analysis. In addition to evaluating small business participation in Federal contracting in terms of the share of total Federal contract dollars awarded to small businesses in each industry, SBA is also assessing the odds of winning Federal contracts

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[16] *See* Shryock , Henry S., Jacob S. Siegel, and associates (1980). *The Methods and Materials of Demography,* 4th Printing, U.S. Department of Commerce, P. 178 (part of the Google Book Search Project).

[17] It should be noted that industries with similar receipts and Gini coefficients can have very different distributions as the Lorenz curves can have different shapes and yet still yield the same Gini coefficient. Despite this limitation, several studies have used the Lorenz curve and Gini coefficient in analyzing industry concentration (*e.g.*, *see* Guth, 1971; White, 1982; Reichardt, 1975; Yeats, 1973).

by small businesses under the current size standard for each industry as part of the Federal contracting factor.

Small Business Shares of Federal Contracts and Industry Receipts

For each industry, SBA compares the small business share of total Federal contract dollars to the share of total industrywide receipts attributed to small businesses. In general, if the share of Federal contract dollars awarded to small businesses in an industry is significantly smaller than the small business share of total industry's receipts, *ceteris paribus*, a justification would exist for considering a size standard higher than the current size standard. In cases where small business share of the Federal market is already appreciably high relative to the small business share of the overall market, it generally becomes a neutral factor in the size standards decision. Based on the FPDS-NG data for FY 2013-2015, small business share of Federal contract dollars shows a wide variation by industry, ranging from a low of 0% to a high of 100%.

The disparity between the small business Federal market share and industrywide share may be attributed to a variety of reasons, including, but not limited to, extensive administrative and compliance requirements associated with Federal contracts, the different skill sets required for performing Federal contracts as compared to typical commercial work, the size and complexity of contracts, specific procurement needs of Federal agencies, and factors influencing the ability of small businesses to enter the Federal market and win contracts. These as well as other factors are likely to influence the type of firms that are able to compete for and win Federal contracts. Firms receiving Federal contracts within an industry are likely to possess different characteristics than the average characteristics for all firms in that industry. Comparing between the Federal market and industrywide shares attributed to small businesses, SBA incorporates Federal market conditions into size standards reviews and analyses.

Odds of Winning Federal Contracts by Small Businesses

The objective of SBA's size standards review is to ensure that small businesses have access to a fair share of Federal government procurements and property sales. To determine how successful or unsuccessful small businesses are in winning Federal contracts in each NAICS industry, as part of the Federal contracting factor, in this revised methodology SBA estimates the odds of winning Federal prime contracts by small businesses under the existing size standards. If the estimated odds of winning Federal contracts for small businesses in an industry are found to be lower relative to the odds of winning contracts for businesses that are other than small, it would suggest that small businesses are not that successful in winning the contracts under the existing size standard for that industry. Small businesses may have the lower odds of receiving Federal contracts in an industry for several reasons, including, but not limited to: (i) the industry is associated with higher capital requirements and other barriers for small businesses to enter the Federal market and win contracts, (ii) small businesses under the industry's current size standard lack adequate technical capabilities, expertise and experience to be able to perform Federal contracts, and (iii) the industry does not have an adequate pool of qualified small businesses, forcing Federal agencies to offer contracts mostly on an unrestricted or full and open competition basis. All else being the same, all these reasons would provide support to increase the size standard.

The principal question of interest here is whether an industry has any difference in terms of the odds or likelihood of winning Federal contracts by small businesses relative to the odds of winning contracts by businesses that are "other than small," while holding constant other factors influencing the likelihood of winning a contract. Economists typically use regression analysis to address this type of question. Such analysis starts with a hypothesis whether there exists any relationship between a variable to be explained (the dependent variable) and one or more explanatory (or independent) variables. In the current context, a pertinent hypothesis to consider is that there exists a significant relationship between a firm's small business status (the independent variable) and whether or not the firm wins Federal contracts (the dependent variable), while controlling for all other relevant variables that may influence the chance of winning contracts.

There are many types of regression analyses being used in practice. However, when the dependent variable is qualitative in nature and represented by the binary, 0-1 dummy variable, the logistic regression model (also known as the logit model) is widely used by economists to estimate the effect of one or more independent variables on the odds (instead of estimating the effect on probability as in the *linear probability model*[18]) of a binary event happening. Specifically, in the current analysis, logistic regression measures the relationship between the binary, 0-1 dummy dependent variable (i.e., the dependent variable is set equal to 1 for firms winning Federal contracts and equal to 0 for those not winning contracts) and such independent variables as the size and age of the firm, its membership in various SBA's small business contracting and business development programs (e.g., 8(a)/BD), HUBZone, WOSB, and SDVOSB), its legal form of organization, its level of government security clearance, and its Federal prime contracting past performance ratings.[19] The logistic regression model with multiple independent variables can be expressed as:

$$y = \frac{P_{win}}{1-P_{win}} = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdot\cdot\cdot + \beta_m x_m + \varepsilon)$$

where y, the dependent variable, is equal to the odds of winning a contract; P_{win} is the probability of winning contracts, *exp*(.) is the exponentiation function; xs are independent variables that influence the odds of whether or not a given firm wins Federal contracts; βs are unknown parameters to be estimated and measure the relationships between individual independent variables and the dependent variable; and the final term, ε, known as the error term, accounts for variables that might influence the dependent variable but are not included in the analysis.

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[18] In the *linear probability model*, the binary or 0-1 dummy dependent variable is regressed on the explanatory or independent variables as in standard multiple linear regression, but its drawback is that the predicted values of the dependent variable or the predicted probabilities may lie outside the 0-1 range.

[19] The Economics and Statistics Administration of the U.S. Department of Commerce applied a similar analysis to determine the NAICS codes in which woman owned businesses (WOBs) are underrepresented or substantially underrepresented in Federal contracting. The link, https://www.sba.gov/sites/default/files/wosb_study_report.pdf, provides a full report of that analysis.

While the above expression of the odds is equivalent to the exponential function of the multiple linear regression expression, the log-odds or the natural logarithm of the odds (the logit) is equivalent to the standard multiple linear regression expression as follows:

$$\ln y = ln\left(\frac{P_{win}}{1-P_{win}}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdot\cdot\cdot + \beta_m x_m + \varepsilon$$

where *ln* is the natural logarithm and the definitions of other terms are the same as in the previous expression.

The exponentiated β-coefficient and the β-coefficient associated with an independent variable represent the effect of a unit change in that independent variable on the odds and the log-odds, respectively. The effect is usually expressed as the ratio comparing the odds (or the log of the odds) after a one unit change in the independent variable to the original odds. Specifically, if x_1 is a continuous variable in the above expressions, β_1 represents the impact of a unit change in x_1 on the log of the odds as:

$$\beta_1 = ln\left(\frac{\frac{P'_{win}}{1-P'_{win}}}{\frac{P_{win}}{1-P_{win}}}\right) = ln\left(\frac{odds'}{odds}\right)$$

where P'_{win} is the probability of winning contracts after a unit change in x_1, while holding constant other independent variables at their mean values. Removing the logarithm by exponentiating both sides yields:

$$e^{\beta_1} = \frac{odds'}{odds}$$

If x_1 is categorical and can take only two values, say 0 and 1 (for example, 1 if a firm qualifies as small and 0 otherwise) the interpretation for β_1 (e^{β_1}) in terms of the log of the odds ratio (the ratio of the odds) becomes:

$$\beta_1 = ln\left(\frac{odds(x_1=1)}{odds(x_1=0)}\right)$$

$$e^{\beta_1} = \frac{odds(x_1=1)}{odds(x_1=0)}$$

In the last example, if the ratio of the odds (simply the odds ratio) or exponentiated value of β_1 (e^{β_1}) is estimated to be more than one, it would indicate that small businesses have the better odds of winning Federal contracts relative to those that are other than small. Conversely, if the estimated odds ratio is less than one, the odds of winning Federal contracts would be lower for small businesses than for those that are other than small.

DATA SOURCES AND ESTIMATION

Industry Data

The primary source of data SBA uses to examine industry characteristics is a special tabulation of the Economic Census from the U.S. Census Bureau (http://www.census.gov/econ/census/).[20] The tabulation based on the 2012 Economic Census is the latest available, which SBA will use for evaluating industry characteristics for the forthcoming five-year comprehensive size standards review. The 2012 special tabulation contains information for different levels of NAICS categories on average and median firm size in terms of both receipts and employment, total receipts generated by the four and eight largest firms, the Herfindahl-Hirshman Index (HHI), the Gini coefficient, and size distributions of firms by various receipts and employment size groupings.

One limitation of the Economic Census special tabulation is that the employees and receipts figures are not fully displayed for some size classes due to disclosure prohibitions, mostly at the 6-digit NAICS industry level. SBA estimates such missing values using the displayed data at the 6-digit level and data at higher levels of industry aggregation, such as at the 2- or 3-digit NAICS level for which such figures are fully displayed.[21] For industries where SBA is not able to estimate missing values for some industry categories, SBA bases its analysis only on those industry factors for which information is complete.

Besides the Economic Census tabulation, SBA may also evaluate relevant industry data from other sources, especially for industries that are not covered by the Economic Census. These include the County Business Patterns published by the U.S. Census Bureau (www.census.gov/programs-surveys/cbp.html), Quarterly Census of Employment and Wages (QCEW, also known as ES-202 data) (www.bls.gov/cew/) and Business Employment Dynamics (BED) data (www.bls.gov/bdm/) from the U.S. Bureau of Labor Statistics, and Census of Agriculture (www.agcensus.usda.gov) from the U.S. Department of Agriculture. Similarly, to evaluate certain financial industries that have assets based size standards SBA examines the data from the Statistics on Depository Institutions (SDI) database (www5.fdic.gov/sdi/main.asp) of the Federal Depository Insurance Corporation (FDIC) data.

Assets Data

As stated above under “Start-up costs and entry barriers,” because of the lack of data on actual start-up costs by industry, SBA uses average assets as a proxy for business start-up costs. For this, SBA combines the sales to total assets ratios by industry, obtained from the Risk

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[20] The special tabulation is similar to the Enterprise Statistics, formerly published by the Census Bureau, except that the Economic Census data is limited to a business operation in its primary industry while the Enterprise Statistics also contained information on operations outside of the primary industry.

[21] For example, because of disclosure restrictions, employee figures in certain cells of size distribution by employment size groups are given in ranges, such as <20, 20-99, 100-249, and so on. Employees values for these cells are estimated using the mid-values of these ranges (such as 10 for <20, 60 for 20-99, 175 for 100-249 and so on) and adjusting these values such that final values are consistent with each industry’s total and total for each size class at a higher level of industry aggregation.. Missing values for receipts in distribution of firms by receipts size are estimated using the employment shares and adjusting the estimated values for internal consistency.

Management Association's (RMA) Annual eStatement Studies (www.rmahq.org/estatement-studies/) with the average firm size (in terms of receipts) by industry from the 2012 Economic Census tabulation to estimate the average assets size for each industry as follows:[22]

$$Average\ assets\ size = \frac{1}{(Sales / Total\ assets)_{RMA}} \times Average\ firm\ size\ (receipts)$$

$$= \left(\frac{Total\ assets}{Sales}\right)_{RMA} \times Average\ firm\ size\ (receipts)$$

The sales to total assets ratios that SBA uses to calculate average assets size are from the RMA's Annual eStatement Studies for 2014-2016.[23]

System for Award Management (SAM)

SBA obtains from the System of Award Management (SAM) (www.sam.gov) the latest data on Federal contractors, more specifically the data on each firm that wants to participate in the Federal procurement market, including size (i.e., number of employees and the average annual revenue), NAICS industry code(s), years of operation, membership in SBA's contracting and business development programs, and organization type. With a few exceptions, a firm should register in SAM before participating in Federal contracting and has to update its SAM information annually. SBA uses the SAM data for evaluating the "exceptions" and size standards for industries that are not covered by any of the industry data sources mentioned above. SAM also provides information on firm specific characteristics for SBA's logistic regression analysis to estimate the odds of winning Federal contracts by small businesses. One limitation of the SAM data is that information is self-reported and includes a large number of outliers and missing values.

Federal Contracting Data

To determine the small business share of total Federal contracting dollars and the odds of winning Federal contracts by small businesses, SBA uses the data from the U.S. General Service Administration's Federal Procurement Data System – Next Generation (FPDS-NG) (www.fpds.gov). The FPDS-NG data is also used for estimating the impacts of size standards revisions. The data contains a range of information on each Federal contract awarded, including name of the company receiving the contract and its small business status, value of the contract, and the NAICS industry code for the goods and service being procured. To determine the Federal contracting factor for the size standards review, SBA generally evaluates the FPDS-NG data for the latest three fiscal years.

The FPDS-NG data also includes employment and revenue information for each contractor. This information is time specific. For example, if a contractor was awarded a

[22] Please refer to www.rmahq.org for further information on the RMA data. One limitation of the RMA data is that sales to assets ratios are not available for a considerable number of industries at the 6-digit NAICS level. For those industries, SBA applies the sales to assets ratios at the 4-digit NAICS level.

[23] SBA will update these data once the more recent data becomes available from RMA.

contract in fiscal year 2011, information about the number of employees and revenue will correspond to that moment in time. By combining the data from FPDS-NG and SAM, SBA obtains the latest available revenues and employees for each contractor.

The FPDS-NG data has several limitations as well. Because most information in FPDS-NG comes from SAM, the FPDS-NG data also suffers from the same problems that pertain to the SAM data. Additionally, the FPDS-NG has the following limitations:

1. FPDS-NG does not allow identifying supply contracts awarded to wholesalers and retailers and differentiating them from those awarded to manufacturers. The system does not include a flag for contracts awarded to nonmanufacturers. Firms providing products to Federal government as nonmanufacturers generally identify themselves with one or more NAICS codes from Sectors 42 or 44-45 and are subject to the 500-employee nonmanufacturer size standard. Thus, revenues and employees information in FPDS-NG corresponds to nonmanufacturers supplying the products, but the NAICS code and dollars obligated under the contract correspond to the industry that manufactures the product. This distorts the relationship between the number of employees and revenues when evaluating the Federal contracting factor for size standards analysis.

2. For industries with “exception(s)” to size standards, the FPDS-NG data does not allow to determine whether the contracting officer applied the regular or “exception” size standard in classifying a contractor as “small” or “other than small.” The data does not include a flag for use of the size standards exceptions.

3. The data needs to be converted from the previous NAICS industry codes to the most recent ones. The NAICS code applied to a specific award remains even though the NAICS code is changed or no longer exists. In some cases, contracting officers continue to use the outdated NAICS codes. These issues warrant a conversion of the data from the old NAICS codes to the most recent NAICS definitions that SBA is using for its size standards.

4. FPDS-NG does not contain information on parent-subsidiary relationships to be able to accurately compute total annual revenue and number of employees for the vertically and horizontally integrated firms.

5. The FPDS-NG data is only limited to prime contracting and does not include information on subcontracting.

6. The FPDS-NG data only includes information on firms that were actually awarded Federal contracts, but not on those who submitted bids for contracts but did not win.

Given the last limitation of the FPDS-data, for logistic regression analysis for determining the odds of winning Federal contracts, SBA constructs a database by merging information on firms from SAM with the data on contract awards from FPDS-NG for the latest three fiscal years. It would be ideal to have the data that includes information both on the characteristics of all firms (e.g., size, years of operation, corporation type, etc.) that apply for contracts and on the characteristics of those contracts (such as contract size, whether or not the contract was set aside for small businesses, whether or not the contract was bundled, etc.). Unfortunately, there exists no such data on all firms that submit bids for Federal contracts.

SAM includes information on firm-specific characteristics, including size (number of employees and average annual receipts), age (years of operation), organization type (e.g., sole proprietorship, partnership, corporation, etc.), identification of NAICS industry or industries, and affiliation with the various SBA's small business contracting and business development programs. FPDS-NG provides information if a firm received a Federal contract during a given period. Firms can identify themselves as operating in or get contracts under multiple NAICS codes. Thus, when the data are analyzed on an industry basis, a firm can appear in the dataset for multiple industries. SBA uses this data to estimate a set of logistic regression models for individual industries relating the odds of winning Federal contracts by firms to their firm-specific characteristics, as listed above. This data does not, however, permit looking at the impact of contract specific characteristics (for example contract size, whether or not contracts were set asides, and so on) on whether or not a firm win contracts, because such information is only available for firms that have won contracts, but not for those that did not win. To examine the effect of contract specific factors on whether not a firm is likely to win contracts within a particular NAICS industry, SBA may perform similar analyses only using the contract awards data from FPDS-NG.

SBA Loan Data

To determine the impact of size standards revisions on SBA's financial assistance, SBA analyzes its internal data on guaranteed loans. For the forthcoming comprehensive size standards review, SBA will use the loan data for fiscal years 2014-2016.

SELECTION OF SIZE STANDARDS

In the methodology applied to the recently completed comprehensive size standards review, SBA adopted a fixed number of size standards levels as part of its effort to simplify size standards. Specifically, for industries with a size standard in average annual receipts, SBA established eight levels of size standards: $5 million, $7 million, $10 million, $14 million, $19 million, $25.5 million, $30 million, and $35.5 million. With the 2014 inflationary adjustment, they are now at $5.5 million, $7.5 million, $10.5 million, $15 million, $20.5 million, $27.5 million, $32.5 million, and $38.5 million. However, there are still 17 different levels of receipts based size standards because of SBA's decision to not lower size standards even though the data supported lowering them for some industries.

Similarly, for manufacturing and other industries with a size standard in terms of employees (except for Wholesale Trade and Retail Trade), SBA applied six standards: 250 employees, 500 employees 750 employees, 1,000 employees, 1,250 employees, and 1,500 employees. For wholesale and retail trade industries with an employee based size standard, SBA used four levels: 100 employees, 150 employees, 200 employees, and $250 employees. In its 2009 "Size Standards Methodology" White Paper, SBA had proposed reducing the minimum size standard for manufacturing industries from 500 employees to 250 employees and the maximum size standard from 1,500 employees to 1,000 employees. However, as discussed elsewhere in this document, in the comprehensive review of the manufacturing size standards, SBA retained both the minimum and maximum standards at 500 employees and 1,500 employees, respectively. Additionally, SBA established a new 1,250-employee size standard between 1,000 employees and 1,500 employees. Similarly, for employee

size standards for the wholesale and retail trade industries, SBA used four of the five levels it proposed in the white paper. The lowest, 50-employee size standard proposed in the methodology was not applied.

In response to public comments to the 2009 methodology white paper, , and the 2013 amendment to the Small Business Act (Section 3(a)(8)) under Section 1661 for the National Defense Authorization Act of Fiscal Year 2013 (NDAA 2013) (P.L. 112-239, Jan. 2, 2013), in this revised methodology, SBA has relaxed the limitation on the number of small business size standards. Specifically, Section 1661 of NDAA 2013 states "SBA cannot limit the number of size standards, and shall assign the appropriate size standard to each industry identified by NAICS."

In this revised methodology, which will be used in the next comprehensive size standards review, SBA is proposing to assign a separate size standard to each NAICS industry. However, to account for errors and limitations associated with various data SBA evaluates in the size standards analysis, SBA proposes to round the calculated value for a receipts based size standard to the nearest $500,000 and the calculated value for an employee based size standard to the nearest 50 employees.[24] As a policy decision, SBA will continue to maintain the minimum and maximum levels for both receipts and employee based size standards. Accordingly, SBA will not generally propose or adopt a size standard that is either below the minimum level or above the maximum, even though the calculations yield values below the minimum or above the maximum. The minimum size standard reflects the size a small business should be to have adequate capabilities and resources to be able to compete for and perform Federal contracts. On the other hand, the maximum size standard represents the level above which businesses, if qualified as small, would outcompete much smaller businesses when accessing Federal assistance. SBA's proposed minimum and maximum size standards are shown in Table 3.

Table 3
Minimum and Maximum Receipts and Employee Based Size Standards

Type of size standards	Minimum	Maximum
Receipts based size standards (excluding agricultural industries in NAICS Subsectors 111 and 112)	$5 million	$40 million
Receipts based size standards for agricultural industries in NAICS Subsectors 111 and 112	$1 million	$5 million
Employee based size standards for Manufacturing and other industries (excluding Wholesale and Retail Trade)	250 employees	1,500 employees
Employee based size standards in Wholesale and Retail Trade	50 employees	250 employees

With respect to receipts based size standards, SBA is proposing $5 million and $40 million, respectively, as the minimum and maximum size standard levels (except for most agricultural industries in Subsectors 111 and 112). These levels reflect the current minimum of $5.5 million and the current maximum of $38.5 million, which are rounded for simplicity. As

[24] SBA may consider using different rounding values for receipts based size standards for agricultural industries and employee based size standards for the wholesale and retail trade industries.

stated earlier, section 1831 of NDAA 2017 amended the Small Business Act directing SBA to establish and review size standards for agricultural enterprises in the same manner it establishes and reviews size standards for all other industries. However, the industry data seems to suggest that $5 million minimum and $40 million maximum size standards would be too high for agricultural industries.

Accordingly, SBA proposes $1 million as the minimum size standard for industries in Subsector 111 (Crop Production) and Subsector 112 (Animal Production and Aquaculture). A vast majority of agricultural industries currently have a $750,000 size standard, which was established by Congress in 2000 (Public Law 106-554, 114 Stat. 2763, Dec. 21, 2000). Considering inflation since then, that is equivalent to a little over $1 million today. Based on the evaluation of the data from the 2012 Census of Agriculture, SBA is proposing $5 million as the maximum size standard for agricultural industries in those two subsectors.[25]

Regarding employee based size standards for manufacturing and other industries (excluding Wholesale and Retail Trade), SBA's proposed minimum and maximum are the current minimum and maximum size standards among those industries. For employee based size standards for wholesale and retail trade industries, the proposed minimum and maximum values are the same as what SBA proposed in its 2009 methodology for them.[26]

EVALUATION OF INDUSTRY FACTORS

As mentioned earlier, to assess the appropriateness of the current size standards SBA evaluates the structure of each industry in terms of four economic characteristics or factors, namely average firm size, average assets size as a proxy of start-up costs and entry barriers, the 4-firm concentration ratio as a measure of industry competition, and size distribution of firms using the Gini coefficient. For each size standard type (i.e., receipts based standards, employee based standards for Manufacturing, etc.), SBA ranks industries both in terms of both each of the four industry factors and in terms of the existing size standard and computes the 20th and 80th percentile values for both.[27] SBA then evaluates each industry by comparing its value for each industry factor to the 20th and 80th percentile values for the corresponding factor for industries under a particular type of size standard, as shown in Table 3 above.

If the characteristics of an industry under review are similar to the average characteristics of industries in the 20th percentile, SBA will consider adopting as an appropriate size standard for that industry the 20th percentile value of size standards for those industries. If the industry's

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[25] NAICS 112112 (Cattle Feedlots) and NAICS 112310 (Chicken Egg Production) currently have a size standard of $7.5 million and $15 million, respectively, and will be subjected to the $5 million minimum and $40 million maximum size standards proposed for other industries.

[26] Current employee based size standards for the wholesale and retail trade industries range from 100 employees to $250 employees. As in the 2009 methodology, SBA is proposing a lower 50-employee level as the minimum employee size standard to account for differences among industries more accurately.

[27] A *percentile* is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations fall. For example, the 20th percentile is the value below which 20% of the observations may be found. There are several methods for calculating the percentiles (see Hyndman and Fan, 1996). The percentile values presented here are based on the averaging percentile method.

characteristics are similar to the average characteristics of industries in the 80th percentile, SBA will assign a size standard that corresponds to the 80th percentile in the size standard rankings of industries. A separate size standard is established for each factor based on the amount of differences between the factor value for an industry and 20th and 80th percentile values for the corresponding factor for all industries in the group. Specifically, actual level of the new size standard for each industry factor is derived by a linear interpolation using the 20th and 80th percentiles of that factor and corresponding percentiles of size standards. Each calculated size standard will be bounded between the minimum and maximum size standards levels, as discussed before. As noted earlier, the calculated value for a receipts based size standard for each industry factor is rounded to the nearest $500,000 and the calculated value for an employee based size standard is rounded to the nearest 50 employees for Manufacturing and industries in other sectors (except Wholesale and Retail Trade) and to the nearest 25 employees for employee based size standards for Wholesale and Retail Trade.

Table 4, below, shows the 20th and 80th percentile values for average firm size (simple and weighted), average assets size, 4-firm concentration ratio, average receipts of the four largest firms, and Gini coefficient for industries with receipts based size standards. Similar results for employee based size standards are presented in Table 5. [28]

Table 4
20th and 80th Percentiles of Industry Factors for Receipts Based Size Standards

Industries/percentiles	Simple average receipts size ($ million)	Weighted average receipts size ($ million)	Average assets size ($ million)	4-firm concentration ratio (%)	Gini coefficient
Industries, excluding Subsectors 111 and 112					
20th percentile	0.83	19.42	0.34	7.9	0.686
80th percentile	7.65	834.75	5.17	42.4	0.835
Industries in Subsectors 111 and 112					
20th percentile	0.06	1.48	0.06	1.7	0.608
80th percentile	0.83	16.54	0.78	12.3	0.908

Table 5
20th and 80th Percentiles of Industry Factors for Employee Based Standards

Industries/percentiles	Simple average firm size (no. of employees)	Weighted average firm size (no. of employees)	Average assets size ($ million)	Four-firm concentration ratio (%)	Gini coefficient
Manufacturing and other industries, excluding Sectors 42 and 44-45					

[28] Figures shown in these and subsequent tables are based on special tabulations of the 2012 Economic Census and Census of Agriculture, and RMA's eStatement Studies data for 2014-2016. They may change when SBA updates industry data or adopts a new analytical procedure. Such changes will be reflected in proposed or final rules.

20th percentile	29.6	251.3	3.92	24.8	0.760
80th percentile	122.7	1,581.6	40.62	61.7	0.853
Industries in Sectors 42 and 44-45					
20th percentile	12.6	199.8	3.22	16.1	0.794
80th percentile	27.9	1,693.8	11.39	38.9	0.865

ESTIMATION OF RECEIPTS BASED SIZE STANDARDS FOR INDUSTRY FACTORS

An estimated size standard supported by each industry factor is derived by comparing its value for a specific industry to the 20th percentile and 80th percentile values for that factor. If an industry's value for a particular factor is near the 20th percentile value in the distribution, the supported size standard will be one that is close to the 20th percentile value of size standards for industries in the size standards group, which is $7.5 million. If a factor for an industry is close to the 80th percentile value of that factor, it would support a size standard that is close to the 80th percentile value in the distribution of size standards, which is $32.5 million. For a factor that is within, above, or below the 20-80 percentile range, the size standard is calculated using linear interpolation based on the 20th and the 80th percentile values for that factor and the 20th and 80th percentile values of size standards. The linear interpolation procedure is explained below, both mathematically and graphically.

Let X = an industry's value for a given industry factor
P_{20} = 20th percentile value for the distribution of the industry factor
P_{80} = 80th percentile value for the distribution of the industry factor
$LSTD$ = 20th percentile of receipts based size standard ($7.5 million)
$HSTD$ = 80th percentile of receipts based size standard ($32.5 million)

Using these notations, a size standard for each industry factor is computed as:

$$\left[\frac{(X-P_{20})}{(P_{80}-P_{20})}\right]\times\left(HSTD-LSTD\right)+LSTD$$

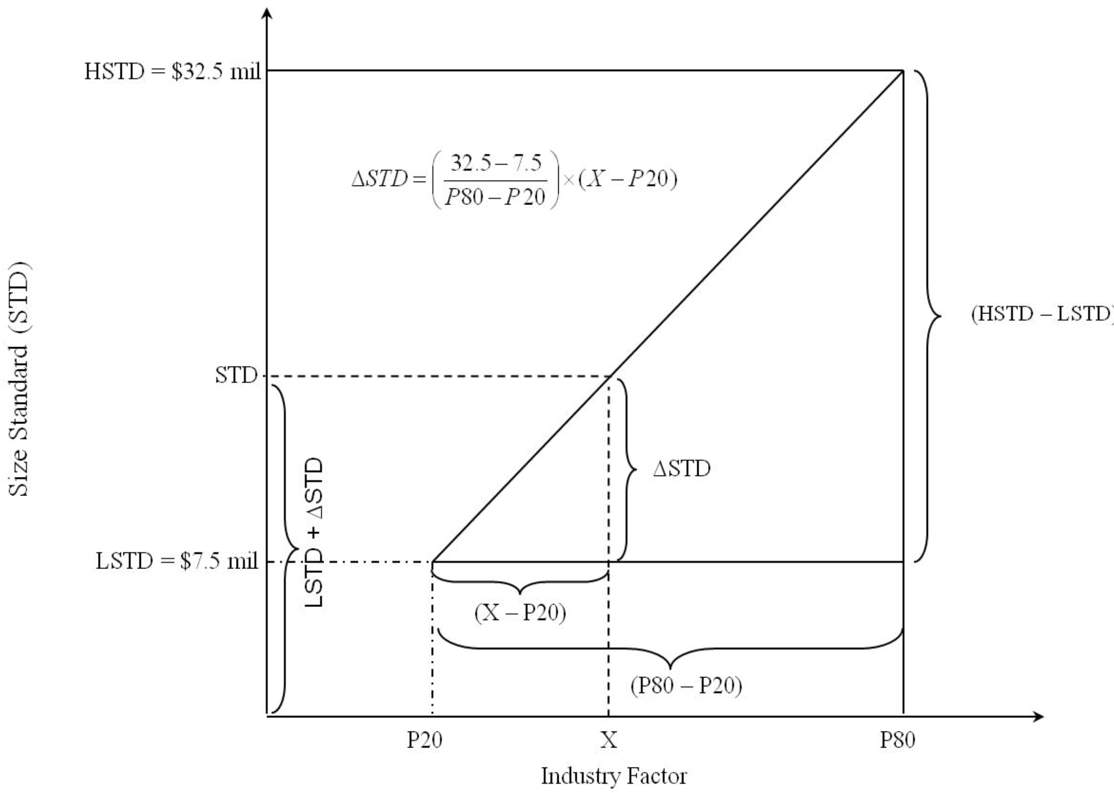
Substituting the 20th percentile (LSTD) and 80th percentile (HSTD) value of size standards yields,

$$\left[\frac{(X-P_{20})}{(P_{80}-P_{20})}\right]\times\left(32.5-7.5\right)+7.5=\left[\frac{(X-P_{20})}{(P_{80}-P_{20})}\right]\times 25+7.5$$

In this expression, the first term in the bracket is the difference between an industry's value for a particular factor and the 20th percentile value of that factor as a proportion of the difference between the 80th percentile value and 20th percentile value of the factor for industries in the same size standard group. Applying this proportion to the difference between the 80th percentile value ($32.5 million) and 20th percentile value ($7.5 million) of size standards yields

an estimated change above or below the 20th percentile size standard. Adding this result to the $7.5 million size standard yields a specific size standard supported by that factor. This procedure is depicted graphically in Figure 3 as well as using some examples, below.

Figure 3. Calculating Receipts Based Size Standard Using Linear Interpolation



$$STD = \left(\frac{(X-P_{20})}{(P_{80}-P_{20})}\right)\times(HSTD-LSTD)+LSTD$$

$$= \left(\frac{(X-P_{20})}{P_{80}-P_{20}}\right)\times(32.5-7.5)+7.5 = \Delta STD + 7.5$$

Receipts Size Standard Based on Average Firm Size

Simple Average Firm Size

A simple average firm size of $1.9 million in receipts would support a size standard of $11.5 million. In this example, X equals $1.9 million, P_{20} equals $0.83 million, and P_{80} equals $7.65 million. Substituting these values in the formula we get,

$$\left[\frac{(X-P_{20})}{(P_{80}-P_{20})}\right]\times 25 + 7.5$$

$$=\left[\frac{(1.9-0.83)}{(7.65-0.83)}\right]\times(32.5-7.5)+7.5=\left[\frac{1.07}{6.74}\right]\times 25+7.5=0.159\times 25+7.5=3.97+7.5=\$11.42 \text{ million.}$$

Rounded to the nearest $500,000, the above result gives a size standard of $11.5 million.

Weighted Average Firm Size

For an industry with a weighted average firm size of $15 million in receipts, all else being equal, $7.5 million would be a supportable size standard. As shown in Table 4, the 20th percentile (P_{20}) and 80th percentile (P_{80}) values of weighted average firm size are $19.42 million and $834.75 million, respectively. Thus, here, X equals $15 million. Substituting these values in the formula, we get,

$$\left[\frac{(X-P_{20})}{(P_{80}-P_{20})}\right]\times 25+7.5=\left[\frac{(15.0-19.42)}{(834.75-19.42)}\right]\times 25+7.5=\left[\frac{-4.42}{815.33}\right]\times 25+7.5$$

$$=-0.005\times 25+7.5=-0.14+7.5=\$7.36 \text{ million.}$$

Rounded to the nearest $500,000, the $7.36 million calculated value becomes $7.5 million.

The size standard supported by the average firm size is calculated as the average of the size standards supported by the simple average firm size and weighted average firm size, rounded again to the nearest $500,000. Accordingly, based on the above examples, the average firm size data supports a $9 million (9 = (11.5+7.5)/2) size standard.

Receipts Size Standard Based on Average Assets Size

If the average assets size of an industry under review is $1.1 million, the appropriate size standard for this factor would be $12 million. As shown in Table 4, the 20th percentile value of the factor is $0.34 million and 80th percentile value is $5.17 million.

Here, X = $1.1 million, P_{20} = $0.34 million, and P_{80} = $5.17 million. Plugging these values in the formula we get,

$$\left[\frac{(X-P_{20})}{(P_{80}-P_{20})}\right]\times 25+7.5=\left[\frac{(1.1-0.34)}{(5.17-0.34)}\right]\times 25+7.5=\left[\frac{0.76}{4.83}\right]\times 25+7.5$$

$$=0.16\times 25+7.5=3.93+7.5=\$11.43 \text{ million}.$$

Rounded this to the nearest $500,000, this gives a size standard of $12 million.

Receipts Size Standard Based on 4-Firm Concentration Ratio

If the four largest firms in an industry account for 45% of total industry receipts the appropriate size standard for this factor will be $34.5 million.

Here, X = 45%, P_{20} = 7.9%, and P_{80} = 42.4%. Substituting these values in the formula we get,

$$\left[\frac{(X-P_{20})}{(P_{80}-P_{20})}\right]\times 25+7.5$$

$$= \left[\frac{(45 - 7.9)}{(42.4 - 7.9)} \right] \times 25 + 7.5$$

$$= \left[\frac{37.1}{34.5} \right] \times 25 + 7.5 = 1.075 \times 25 + 7.5 = 26.88 + 7.5 = \$34.38 \text{ million.}$$

Rounded to the nearest 500 thousand, this gives a size standard of \$34.5 million.

Receipts Size Standard Based on Gini Coefficient

If an industry's size distribution produces a Gini coefficient value of 0.67, its size standard for this factor would be \$5 million. The 20th percentile of the estimated Gini coefficient value is 0.686 and the 80th percentile value of 0.835 (Table 4).

Thus, for this example, X = 0.67, P_{20} = 0.686, and P_{80} = 0.835. Substituting these values in the formula we get,

$$\left[\frac{(X - P_{20})}{(P_{80} - P_{20})} \right] \times 25 + 7.5$$

$$= \left[\frac{(0.670 - 0.686}{(0.835 - 0.686)} \right] \times 25 + 7.5 = \left[\frac{-0.016}{0.149} \right] \times 25 + 7.5$$
$$= -0.107 \times 25 + 7.5 = -2.68 + 7.5 = \$4.82 \text{ million.}$$

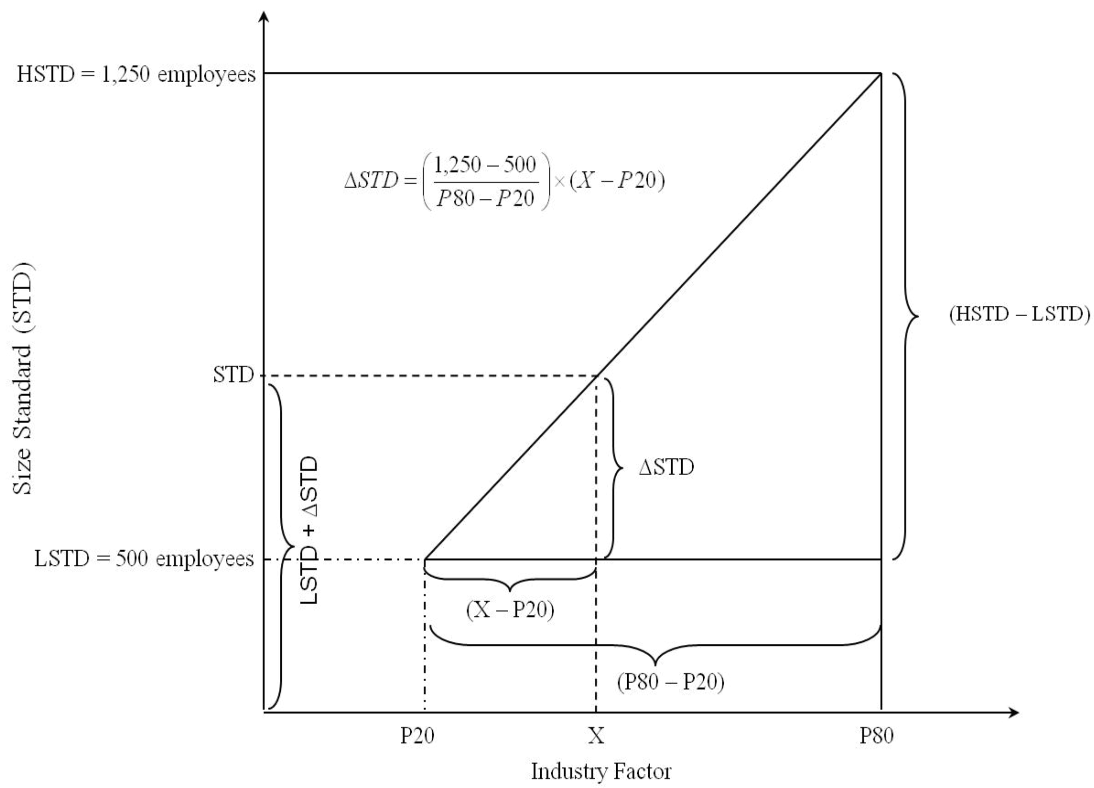
Rounded to the nearest \$500,000, this gives a size standard of \$5 million.

ESTIMATION OF EMPLOYEE BASED SIZE STANDARDS FOR INDUSTRY FACTORS

Manufacturing and Other Industries Not in Wholesale and Retail Trade

Employee based size standards for the manufacturing and other industries (except Wholesale Trade and Retail Trade) with an employee based size standard are established in the same manner as receipts based standards, as described above. That is, a separate employee based size standard is established for each industry factor for each industry using the 20th and the 80th percentile values of each industry factor and the 20th and the 80th percentile values of employee based size standards for those industries. The 20th percentile and 80th percentile values of employee based size standards for manufacturing other industries (excluding Wholesale Trade and Retail Trade) are 500 employees and 1,250 employees, respectively. The linear interpolation procedure for deriving an employee based size standard is depicted in Figure 4.

Figure 4. Calculating Employee Based Size Standards Not Part of Wholesale and Retail Trade



$$STD = \left(\frac{(X - P_{20})}{(P_{80} - P_{20})}\right) \times (HSTD - LSTD) + LSTD$$

$$= \left(\frac{(X - P_{20})}{P_{80} - P_{20}}\right) \times (1{,}250 - 500) + 500 = \Delta STD + 500$$

Using the similar notations used for receipts based size standards above,

X = an industry's value for a given industry factor

P_{20} = 20th percentile value for the distribution of the industry factor

P_{80} = 80th percentile value for the distribution of the industry factor

$LSTD$ = 20th percentile of receipts based size standard (500 employees)

$HSTD$ = 80th percentile of receipts based size standard (1,250 employees)

An employee size standard for each industry factor is computed as:

$$\left[\frac{(X - P_{80})}{(P_{80} - P_{20})}\right] \times (HSTD - STD) + LSTD$$

$$= \left[\frac{(X - P_{20})}{(P_{80} - P_{20})}\right] \times (1{,}250 - 500) + 500 = \left[\frac{(X - P_{20})}{(P_{80} - P_{20})}\right] \times 750 + 500$$

The above formula yields an estimated size standard for each factor, which is then rounded to the nearest 50 employees between 250 employees (minimum) and 1,500 employees (maximum).

Wholesale Trade and Retail Trade

Employee size standards for the wholesale and trade industries are also derived using a similar procedure described above for receipts and employee based size standards for other industries. Accordingly, a separate employee based size standard is computed for each industry factor for each industry using the 20th and the 80th percentile values of each factor and the 20th and the 80th percentile values of employee based size standards for those industries. The 20th percentile and 80th percentile values of employee based size standards for the wholesale trade and retail trade industries are 100 employees and 200 employees, respectively. The linear interpolation procedure for deriving a wholesale or retail trade employee based size standard is depicted in Figure 5.

Using the above notations, an employee based size standard for each industry factor for a wholesale or retail trade industry is computed as follows:

X = an industry's value for a given industry factor

P_{20} = 20th percentile value for the distribution of the industry factor

P_{80} = 80th percentile value for the distribution of the industry factor

$LSTD$ = 20th percentile of receipts based size standard (100 employees)

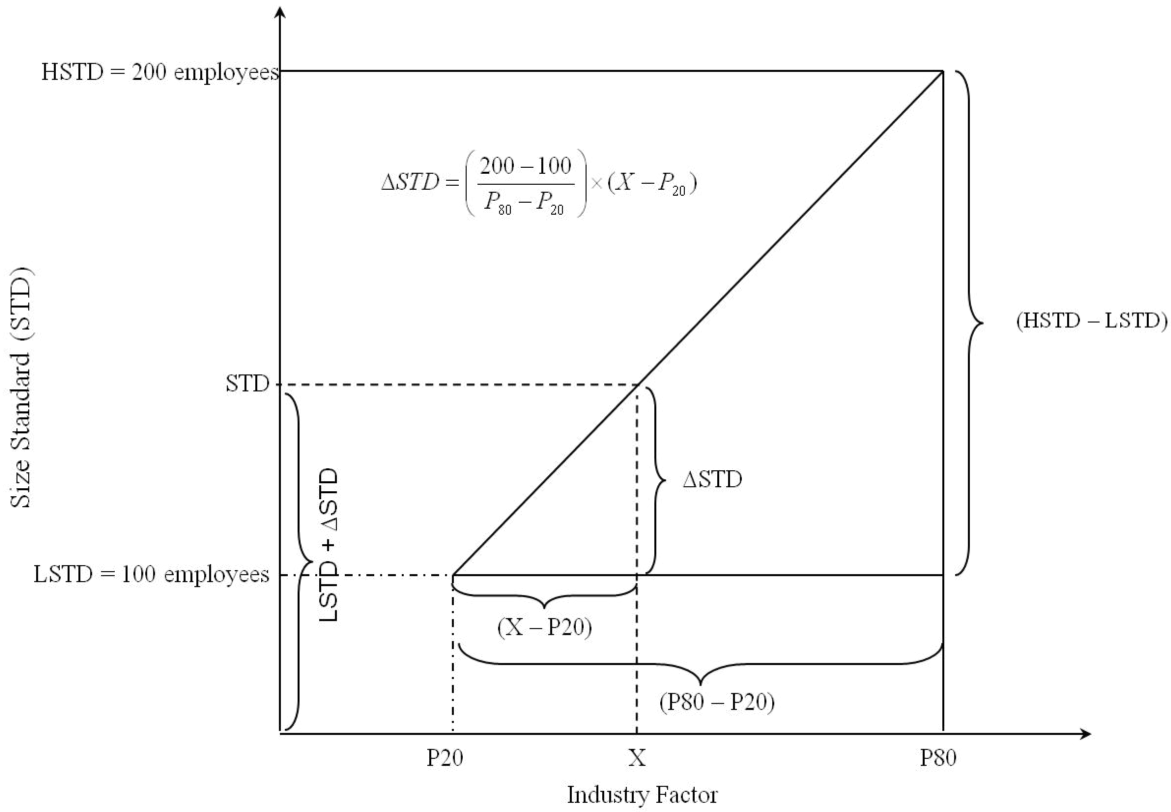
$HSTD$ = 80th percentile of receipts based size standard (200 employees)

$$\left[\frac{(X - P_{80})}{(P_{80} - P_{20})}\right] \times \left(HSTD - STD\right) + LSTD$$

$$= \left[\frac{(X - P_{20})}{(P_{80} - P_{20})}\right] \times \left(200 - 100\right) + 100 = \left[\frac{(X - P_{20})}{(P_{80} - P_{20})}\right] \times 100 + 100$$

The above formula yields an estimated size standard for each factor, which is then rounded to the nearest 25 employees

Figure 5. Calculating Employee Based Size Standards for Wholesale and Retail Trade



$$STD = \left(\frac{(X-P_{20})}{(P_{80}-P_{20})}\right)\times\left(HSTD-LSTD\right)+LSTD$$

$$= \left(\frac{(X-P_{20})}{P_{80}-P_{20}}\right)\times(200-100)+100 = \Delta STD+100$$

EVALUATION OF FEDERAL CONTRACTING FACTORS

SBA considers Federal contracting as one of the primary factors when establishing, reviewing, or revising size standards. In this revised methodology, SBA evaluates the Federal contracting factor for industries with \$20 million or more in Federal contract dollars annually for the latest three fiscal years. SBA determines that a size standard revision would not have a significant impact below that level of Federal contracting activity. The latest FPDS-NG data suggests that the \$100 million threshold used in the 2009 methodology is too high, rendering the Federal contracting factor irrelevant for more than 80% of industries.

As explained earlier, in this revised methodology, SBA considers two measures of Federal contracting for each industry with \$20 million or more in Federal contracts: (i) the difference between small business shares of total Federal contracts and total industry' receipts, and (iii) the odds of winning Federal contracts by small businesses.

Because NAICS codes in Wholesale Trade (Sector 42) and Retail Trade (Sector 44-45) do not apply to Federal procurement, SBA does not consider the Federal contracting factor for evaluating size standards industries in those sectors.

Small Business Shares of Total Federal Contracts and Industry Receipts

To determine if small businesses in an industry are receiving a fair share of Federal contracts, SBA computes the small business shares of Federal contracting dollars and industry total receipts as follows:

$$\textit{Small business share in Federal contracts}$$

$$= \frac{\textit{Total Federal contracting dollars awareded to small businesses in an industry}}{\textit{Total Federal contracting dollars awarded under that industry}}$$

$$\textit{Small business share in industry total receipts}$$

$$= \frac{\textit{Total industry's receipts attributable to small businesses in an industry}}{\textit{Total industry's receipts in that industry}}$$

All other factors being equal, if the share of Federal contracting dollars awarded to small businesses in an industry is significantly less than the small business share of that industry's total receipts, a justification would exist for considering a size standard higher than the current size standard. Conversely, if the small business share of Federal contracting activity is near or above the small business share in total industry receipts, this will support the current size standard.

Odds of Winning Federal Contracts by Small Businesses

To determine the odds of winning Federal contracts by small businesses relative to their large business counterparts, SBA estimates logistic regression for each NAICS industry (excluding industries in NAICS Sectors 42 and 44-45) with $20 million or more in average annual Federal contracts during fiscal years 2013-2015. For this, SBA uses information on firms that are either identified with an industry in SAM or received a Federal contract under that industry either in FY 2014 or in FY 2015. In cases where the sample is too small for the analysis at the 6-digit NAICS industry level, SBA conducts the analysis at the 4-digit NAICS Industry Group level and applies the results to all 6-digit industries within the group. The dependent and independent variables for logistic regression are explained below and summarized in Table 6.

As stated earlier, the dependent variable in logistic regression is associated with two outcomes. In the current context, for each industry, firms are considered either "winners" of contracts if they received contracts in that NAICS code during the period of analysis or "non-winners" if they received no contracts. Specifically, the *dependent variable* (y) is set equal to 1 for firms who won Federal contracts and equal to 0 for those who did not. SBA includes the following independent variables in estimating a logistic regression model for each industry.

Table 6
Summary of Dependent and Independent Variables for Logistic Regression

	Small			Large			Total		
	Winner	Non-winner	All small	Winner	Non-winner	All large	Winner	Non-winner	All
No. of observations	118,999	259,878	378,877	16,555	30,614	47,169	135,554	290,492	426,046
Mean values of indicator or dummy (0, 1) variables									
Dependent variable (y)	1.000	0.000	0.3141	1.000	0.000	0.3510	1.000	0.000	0.3182
Small business (x_1)	1.000	1.000	1.000	0.000	0.000	0.000	0.8779	0.8946	0.889
SBA certified and SDB (x_2)	0.2564	0.3878	0.3465	0.0206	0.0270	0.0248	0.2276	0.3498	0.3182
Ownership (x_3)	0.4019	0.4669	0.4465	0.0421	0.0527	0.0490	0.3580	0.4233	0.4025
Sole proprietor (x_7)	0.1725	0.1842	0.1806	0.0031	0.0060	0.0050	0.1518	0.1655	0.1611
Partnership (x_8)	0.0966	0.1413	0.1272	0.0852	0.0880	0.0870	0.0952	0.1356	0.1228
Corporation (x_9)	0.6367	0.5929	0.6066	0.8228	0.8243	0.8238	0.695	0.6172	0.6307
Profit orientation (x_{10})	0.9619	0.9279	0.9386	0.9076	0.9124	0.9107	0.9552	0.9263	0.9355
Government security (x_{11})	0.937	0.0444	0.0599	0.1531	0.0736	0.1015	0.1010	0.0475	0.0645
Median values of continuous variables									
Experience (x_4) (years)	17	10	13	30	25	27	18	12	14
Number of employees (x_5)	10	4	5	3,500	3,000	3,277	14	5	7
Avg. revenue (x_6) ($1,000)	1,500	362	595	663,800	541,500	574,700	2,200	546	900

Small business (x_1): 1 if the firm qualified as small for an industry, 0 otherwise;

SBA certified and SDB (x_2): 1 if the firm is an 8(a), HUBZone or socially disadvantaged business, 0 otherwise;

Ownership (x_3): 1 if the firm is a minority, woman, service disabled or other veteran owned business, 0 otherwise;

ln*Experience* (x_4): natural logarithm of the number of years the firm has been in operation;

ln*Employees* (x_5): natural logarithm of the firm's number of employees in SAM;

ln*Revenue* (x_6): natural logarithm of the firms' average annual revenue in SAM;

Business organization – sole proprietor (x_7): 1 if the firm is a sole proprietor, 0 otherwise;

Business organization – partnership (x_8): 1 if the firm is organized as partnership, 0 otherwise;

Business organization – corporation (x_9): 1 if the firm is organized as corporation, 0 otherwise;

Profit orientation (x_{10}): 1 if the firm is operated for profit, 0 otherwise; and

Government security clearance (x_{11}): 1 if the firm has confidential, secret, or top-secret security status, 0 otherwise.

Of particular interest here is the *small business* variable. The coefficient or odds ratio associated with the *small business* variable in the estimated model would indicate whether businesses that qualify as small under an industry's current size standard have a higher or lower likelihood of winning a Federal contract relative to businesses that are other than small. Specifically, a positive coefficient or an odds ratio of more than one would suggest that a business that qualifies as small under the current size standard would, all other variables being the same, have a better chance of winning a Federal contract than a business that is other than small. Conversely, a negative coefficient or an odds ratio that is less than one would suggest that a small firm under the existing size standard has lower likelihood of winning a contract as compared to its large business counterpart. The latter result would support an increase to an existing size standard.

CALCULATING SIZE STANDARDS BASED ON FEDERAL CONTRACTING FACTORS

Small Business Shares of Federal Contracts and Industry Receipts

In the 2009 methodology, SBA designated a size standard at one level higher than the existing current size standard for industries where the small business share of total industry receipts was between 10 and 30 percentage points higher than the small business share of total Federal contract dollars and at two levels higher than the existing size standard where that difference was more than 30 percentage points. When that difference was less than 10 percentage points or when the small business share of Federal contracts was more than the small business share of total industry receipts, SBA assumed that the existing size standard was appropriate with respect to the Federal contracting factor.

The above procedure worked well for the recently completed comprehensive size standards review where SBA used a limited number of size standards. With the limitation on the number of size standards relaxed in accordance with NDAA 2013, that procedure is no longer applicable. Accordingly, in this revised methodology, SBA proposes to increase the existing size standards by certain percentages when the small business share of total industry receipts exceeds the small business share of total Federal contract dollars by 10 or more percentage points. Proposed percentage increases generally reflect receipts and employee levels needed to bring the small business share of Federal contracts at par with the small business share of industry receipts. These proposed percentage increases are given in Table 7.

For example, let's assume that an industry with the current size standard of $7.5 million had an average of $50 million in Federal contracting dollars during FY 2013-2015, of which 15% went to small businesses. Let's also assume that small businesses accounted for 40% of total receipts of that industry. Thus, in this case, the small business share of total industry receipts is 25% more than the small business share of total Federal contract dollars. According to the above rule, the new size standard for that industry would be set by multiplying $7.5 million by 1.3 and then by rounding the result to the nearest $500,000, yielding a size standard of $10 million.

Table 7
Proposed Adjustments to Size Standards for Small Business Share of Federal Contracts

Size standards	Percentage difference between the small business shares of total industry receipts and of total Federal contract dollars in an industry		
	< 10%	10–30%	> 30%
Receipts based standards			
< $15 million	No change	Increase 30%	Increase 60%
$15 million to < $25 million	No change	Increase 20%	Increase 40%
$25 million to < $40 million*	No change	Increase 15%	Increase 25%
Employee based standards			
< 500 employees	No change	Increase 30%	Increase 60%
500 to < 1,000 employees	No change	Increase 20%	Increase 40%
1,000 to < 1,500 employees*	No change	Increase 15%	Increase 25%

* Adjusted receipts and employee based standards will be capped at $40 million ($5 million for industries in Subsectors 111 and 112) and 1,500 employees, respectively.

Odds of Winning Federal Contracts by Small Businesses

SBA estimates the unknown parameters of the logistic regression model for each industry that has $20 million or more in annual Federal contracts. For illustration purposes, the results of the estimated logistic regression models for three NAICS industries are shown in Table 8, below.

As explained before, if the odds of winning Federal contracts for small businesses in an industry are found to be significantly lower than the corresponding odds for businesses that are other than small, the results would support an increase to that industry's current size standard. On the other hand, if the odds of winning Federal contracts are significantly higher for small businesses than for their other-than-small counterparts, SBA would presume that the existing size standards are adequate for Federal contracting purposes. A statistically insignificant difference between the odds for the two groups would also support the existing size standard.

For this, SBA specifically looks at the parameter estimates and odds ratios associated with the *small business* (x_1) variable in the estimated logistic regression models. If the estimate for the *small business* variable for an industry is found to be negative and significant and the corresponding odds ratio is lower than one (i.e., the case of NAICS 332312 in Table 8), this would suggest that a business qualifying as small under that industry's existing size standard has the lower odds of winning a Federal contract as compared to a business that is other than small, while holding constant other variables that might influence a firm's chance of winning a contract. This would provide a justification to adjust the current size standard upwards. On the other hand, if the coefficient associated with the *small business* variable is positive and significant and the odds ratio is more than one (i.e. the case of NAICS 236210 in Table 8), the result would indicate that small businesses enjoy the higher odds of winning a contract than those that are other than small. This would justify maintaining the current size standard. If the estimated coefficient is not significant (the case of NAICS 541360 in Table 8) that would also support retaining the current standard.

Table 8
Logistic Regression Results for Some NAICS Industries
(*dependent variable* (*y*) = 1 if contract winner, 0 otherwise)

	NAICS 236210 n = 17583		NAICS 332312 n = 3975		NAICS 541360 n = 4085	
Independent variable	Estimate	Odds ratio	Estimate	Odds ratio	Estimate	Odds ratio
Constant	-7.100**	< 0.001	-2.232**	0.107	-1.948**	0.143
	(0.482)		(0.547)		(0.653)	
***Small business* (x_1)**	**0.953****	**2.593**	**-0.685****	**0.504**	**-0.323**	**0.724**
	(0.170)		(0.220)		(0.288)	
SBA certified and SDB (x_2)	0.366**	1.442	-0.611**	0.543	-0.434*	0.648
	(0.089)		(0.103)		(0.215)	
Ownership (x_3)	0.568**	1.764	-0.043	0.958	-0.690**	0.502
	(0.093)		(0.089)		(0.207)	
ln*Experience* (x_4)	0.234**	1.263	0.347**	1.415	0.321**	1.378
	(0.053)		(0.053)		(0.098)	
ln*Employees* (x_5)	-0.106**	0.900	-0.133*	0.876	-0.140**	0.869
	(0.038)		(0.043)		(0.062)	
ln*Revenue* (x_6)	0.270**	1.310	0.104**	1.109	0.021**	1.022
	(0.028)		(0.024)		(0.035)	
Sole proprietor (x_7)	-0.785**	0.456	0.409	1.506	0.270	1.311
	(0.244)		(0.217)		(0.346)	
Partnership (x_8)	-0.415**	0.660	0.014	1.014	-0.428	0.652
	(0.162)		(0.198)		(0.396)	
Corporation (x_9)	-0.147	0.863	0.012	1.012	-0.142	0.868
	(0.109)		(0.141)		(0.255)	
Profit orientation (x_{10})	-1.579	0.206	-0.441	0.644	-1.095**	0.335
	(0.172)		(0.370)		(0.299)	
Government security (x_{11})	0.304	1.355	0.292	1.339	-0.281	0.755
	(0.124)		(0.146)		(0.222)	

Note: n = number of observations.
Figures in parentheses are standard errors for parameter estimates.
** and * denote the 5% and 10% level of significance, respectively.

Of all 6-digit NAICS industries for which SBA establishes size standards (excluding those in Wholesale and Retail Trade for which the Federal contracting factor does not apply), SBA estimated a separate logistic regression model for each of the 408 industries that averaged $20 million or more in annual Federal contract dollars during fiscal years 2013-2015. Table 9, below, shows the distribution of industries by the magnitude and level of significance of the estimated odds ratios for the *small business* variable. As can be seen from the table, 60 of the industries have the odds ratios that are significantly smaller than one at the 5% level of significance. At the 10% significance level, that figure increases to 78.[29] That means that businesses that qualify as small under the existing size standard in those industries have the significantly lower odds of winning Federal government contracts than those that are other than

[29] For purposes of this analysis, SBA proposes to use the 10% level of significance. That, also known as type I error, is the probability of rejecting the hypothesis that the odds ratio is not different from zero when it is true.

small, when other possible variables influencing the likelihood of winning a contract are controlled. This result would support an upward adjustment to the existing size standard for those industries.

Table 9

Distribution of Industries by the Estimated Odds Ratio for the Small Business Variable

The odds ratio (1)	Significant at 5% (2)	Significant at 10% (3)	Not significant (4)	Total (3 +4)
< 0.5	41	48	12	60
0.5 to < 0.75	18	27	44	71
0.75 to < 1.0	1	3	63	66
≥ 1.0	89	105	106	211
Total	149	183	225	408

On the other hand, for 89 industries (105 at the 10% significance level), the odds ratios for the *small business* variable are significant and more than one, meaning that small businesses in those industries have a significantly higher likelihood of winning a Federal contract than those that do not qualify as small. In those industries as well as in others where the odds ratios are not significant, SBA presumes that the existing size standards are adequate for purposes of Federal contracting.

SBA proposes to adjust the current size standards based on the odds ratio for *the small business* variable as shown in Table 10, below. These proposed adjustments result in fairly similar absolute changes to different levels of size standards.

Table 10

Proposed Adjustments to Size Standards Based on the Odds of Winning Federal Contracts

	The odds ratio associated with the small business variable			
Size standards	Nonsignificant or significant and > 1	Significant and 0.75 to < 1	Significant and 0.5 to < 0.75	Significant and < 0.5
Receipts based standards				
< \$15 million	No change	Increase 30%	Increase 40%	Increase 60%
\$15 million to < \$25 million	No change	Increase 20%	Increase 30%	Increase 40%
\$25 million to < \$40 million*	No change	Increase 15%	Increase 20%	Increase 25%
Employee based standards				
< 500 employees	No change	Increase 30%	Increase 40%	Increase 60%
500 to < 1,000 employees	No change	Increase 20%	Increase 30%	Increase 40%
1,000 to < 1,500 employees*	No change	Increase 15%	Increase 20%	Increase 25%

* Adjusted receipts and employee based standards will be capped at \$40 million (\$5 million for industries in Subsectors 111 and 112) and 1,500 employees, respectively.

DERIVATION OF COMPOSITE SIZE STANDARD AND WEIGHTING METHOD

SBA methodology presented above results in five separate size standards based on evaluation of the five primary factors. The value for each of the five factors for a hypothetical industry and the corresponding receipt based size standard supported by each factor are summarized in Table 11. Also shown in the table is the derivation of the composite size standard for the five primary factors. The simple average of five size standards based on each of the five factors is $15.1 million. Rounded to the nearest $500,000, this becomes $15 million. The simple average method weighs all factors equally. The composite size standard for employee based standards can also be derived in a similar fashion. SBA can assign different weights to some of these factors in response to its policy decisions and other considerations.

Table 11
An Example of Deriving the Composite Size Standard

Primary factor	Factor value	Size standard (STD) ($ million)	
1. Average firm size (AFS) [a]			11.0
1.1. Simple average firm size ($ mil.)	1.9	11.5	} 11.0
1.2. Weighted average firm size ($ mil.)	15.0	7.5	
2. Average assets size (AAS) ($ million)	1.1		12.0
3. Four-firm concentration ratio (CR4) (%)	45.0		34.5
4. Size distribution of firms (Gini coefficient) (GINI)	0.67		5.0
5. Federal contracting (CONTRACT) [b]			13.0
5.1. Difference between small business shares of industry receipts and of Federal contract dollars	25%	10.0	} 13.0
5.2. The odds ratio of winning Federal contracts by small businesses	0.65	15.5	
Average (composite) size standard (AVGSTD)			15.0

[a] Note that the size standard for average firm size is computed as an average of size standards supported by simple average firm size and weighted average firm size, rounded to the nearest $500.000.

[b] The size standard for the Federal contracting factor is derived as an average of size standards supported by each of the two components of the Federal contracting factor, rounded to the nearest $500.000.

As shown below in Table 11, SBA evaluates five primary factors in establishing, reviewing or modifying size standards. In the example provided, SBA is assigning the same weight to each of the five factors.[30] However, if necessary, the methodology allows altering the

30 $AVGSTD = \frac{[STD_{AFS} + STD_{AAS} + STD_{CR4} + STD_{GINI} + STD_{CONTRACT}]}{5}$

weights for individual factors for certain industries.[31] If SBA decides to alter these weights it will explain in the proposed rule how the various factors are weighed in devising a size standard for industries involved. While each factor is examined for every industry, the importance of each factor within each group may vary according to the characteristics of each industry. This method ensures consistency of approach while maintaining sufficient flexibility in establishing a size standard for each industry.

IMPACTS OF CHANGES IN THE METHODOLOGY

To determine how the changes in the size standards methodology would affect size standards across various industries and sectors, SBA derived the new size standards using the "anchor" approach and the "percentile" approach for all industries (except those in Sectors 42 and 44-45, and industries in Subsectors 111 and 112 that currently have the statutory $750,000 size standard)[32]. For receipts based size standards, the anchor group consisted of industries with the $7.5 million size standard, and the higher size standard group included industries with the size standard of $25 million and higher, with the weighted average size standard of $33.2 million for the group. Similarly, for employee based size standards, the anchor group comprised industries with the 500-employee size standard, and higher size standard group comprised industries with size standard of 1,000 employees and above, with the weighted average size standard of 1,182 employees. These and 20th and 80th percentile values for receipts and employee based size standards are shown, below, in Table 12.

Table 12

Reference Size Standards under Anchor and Percentile Approaches

	Anchor Approach		Percentile Approach	
	Anchor level	Higher level	20th percentile	80th percentile
Receipts standard ($ million)	$7.5	$33.2	$7.5	$32.5
Employee standard (no. of employees)	500	1,182	500	1,250

Under the anchor approach, as described previously, we derived the average value of each industry factor for industries in the anchor groups as well as those in the higher size standard groups for both receipts based and employee based size standards. These results are provided in Table 13. In the percentile approach, the 20th percentile and 80th percentile values were computed for each industry factor. Those results are provided in Tables 4 and 5, above. However, for comparison, the results for the percentile approach are also shown in Table 13. As

$$= 0.2 \cdot STD_{AFS} + 0.2 \cdot STD_{AAS} + 0.2 \cdot STD_{CR4} + 0.2 \cdot STD_{GINI} + 0.2 STD_{CONTRACT}$$

31 $$AVGSTD = w_{AFS} \cdot STD_{AFS} + w_{AAS} \cdot STD_{AAS} + w_{CR4} \cdot STD_{CR4} + w_{GINI} \cdot STD_{GINI} + w_{CONTRACT} STD_{CONTRACT}$$
$$where \quad ws\ are\ weights\ and\ w_{AFS} + w_{AAS} + w_{CR4} + w_{GINI} + w_{CONTRACT} = 1.0$$

32 For this part of the analysis, industries in Sectors 42 and 44-45 were excluded as NAICS codes in those sectors do not apply to Federal procurement. Similarly, most industries in Subsectors 111 and 112 were also excluded because they are different from other industries and should be evaluated separately.

can be seen from the table, for most industry factors, the anchor values are comparable to the 20th percentile values and higher level values are comparable to the 80th percentile values.

Table 13

Industry Factors under the Anchor and Percentile Approaches

	Anchor Approach		Percentile Approach	
	Anchor	Higher level	20th percentile	80th percentile
Industry factors for receipts based size standards, excluding Subsectors 111 and 112				
Simple average receipts size ($ million)	0.78	7.09	0.83	7.65
Weighted average receipts size ($ million)	18.07	724.84	19.42	834.75
Average assets size ($ million)	0.35	4.73	0.34	5.17
4-firm concentration ratio (%)	10.4	34.5	7.9	42.4
Gini coefficient	0.679	0.830	0.686	0.835
Industry factors for employee based size standards, excluding Sectors 42 and 44-45				
Simple average firm size (no. of employees)	33.4	98.2	29.6	122.7
Weighted average firm size (no. of employees)	232.2	1,362.6	251.3	1,581.6
Average assets size ($ million)	4.82	23.29	3.92	40.62
4-firm concentration ratio (%)	24.8	50.3	24.8	61.7
Gini coefficient	0.770	0.842	0.760	0.853

Under the anchor approach, using the anchor size standard and average size standard for the higher size standard group, SBA computed a size standard for an industry's characteristic (factor) based on that industry's position for that factor relative to the average values of the same factor for industries in the anchor and higher size standard groups. Similarly, as explained previously, for the percentile approach, combining the factor value for an industry with the 20th and 80th percentile values of size standards and industry factors among the industries, SBA computed a size standard supported by each industry factor for each industry. Under the both approaches, to comply with section 3(a)(8) of the Act, a calculated receipts based size standard was rounded to the nearest $500,000 and a calculated employee based size standards was rounded to the nearest 50 employees. The anchor approach that the Agency used in the recent review of the size standards used a limited number of fixed size standards levels.

With respect to the Federal contracting factor, for each industry averaging $20 million or more in Federal contracts annually, SBA considered under both approaches the difference between the small business share of total industry receipts and that of Federal contract dollars as well as the estimated odds that small businesses win Federal contracts under the current size standards. Specifically, the existing size standards would increase by certain percentages when the small business share of total industry receipts exceeds the small business share of total Federal contract dollars by 10 or more percentage points. Those percentage increases (shown in Table 7, above) to size standards generally reflect receipts and employee levels needed to bring

the small business share of Federal contracts at par with the small business share of industry receipts. If the odds that small businesses win Federal contracts for in an industry are found to be significantly lower than one, the results would support an increase to that industry's current size standard (the increase would depend on the estimated odds and level of current size standard as shown in Table 10, above). Otherwise, the results would support the existing size standard.

The calculated size standards were quite similar between the two approaches when compared to the existing size standards, with size standards increasing for some industries and decreasing for others under both approaches. Most impacted sector was NAICS Sector 23 (Construction), with a majority of industries in the sector experiencing decreases to the current size standard. Overall, the changes to size standards as the result of the changes in the methodology, if adopted, would have a very minimal impact on number of businesses that qualify as small. Excluding NAICS Sectors 42 and 44-45, and Subsectors 111 and 112, 97.73 percent of businesses would qualify as small under the calculated size standards obtained from the anchor approach vs. 97.68 percent under the percentile approach. That figure is also 97.73 percent under the current size standards.

IMPACT OF PREVIOUS SIZE STANDARDS REVISIONS ON FEDERAL CONTRACTS TO SMALL BUSINESSES

On top of industry and Federal contracting factors discussed above, SBA also assesses the impacts of size standards revisions it made in the previous round of the comprehensive size standards review when making adjustments in the next round. Specifically, for each industry for which the size standard was revised, SBA evaluates the share of Federal contract dollars awarded to businesses that were small under the old size standard. If their share of Federal contract dollars decreased significantly under the revised size standard, SBA may consider proposing or adopting a size standard that is different from one supported by industry and Federal contracting factors. For example, let's consider a hypothetical industry whose size standard increased from $7 million to $14 million. If the analysis shows that the share of that industry's total small contract dollars awarded to businesses below the old, $7 million size standard decreased significantly under the revised size standard and most of those dollars went to the newly qualified businesses between $7 million and $14 million, SBA may consider maintaining, or in some cases even lowering, the current size standard even if the evaluation of the primary factors may suggest increasing the size standard for that industry. This is to ensure that revisions to size standards do not cause an adverse impact on businesses that were small under the old size standards.

SECONDARY FACTORS

In addition to the primary factors discussed above, there are others factors, which SBA may consider in deciding a size standard. As in the case of primary factors, not all of the secondary factors would be applicable in every industry, but each will be evaluated to see to what extent they are relevant. These factors will not by themselves have a direct impact on a size standard and thus are of secondary importance. SBA will consider these factors on a case-by-case basis when reviewing size standards. Five such factors are discussed next.

Technological Change

This factor can have an impact on the production process or productivity of labor and other inputs in an industry. It can result in fundamental shifts in the way firms operate and conduct business within an industry and can revolutionize the entire industry sector. If a change in a manufacturing industry is geared toward more automation, for example, a fewer employees can produce the same amount of output. This may warrant adjusting that industry's size standard downward.

Competing or Similar Products or Services among Industries

This factor has to do with the way industries are defined under the NAICS. SBA uses NAICS as the basis of industry definitions for size standards purposes. NAICS is used both inside and outside the government as a uniform framework for classifying economic activities for the purpose of collecting establishment statistics on the nation's economy.

NAICS classifies establishments with similar production processes in the same industry. A market, on the other hand, is made up of a group of substitutable or competing products.[33] While there are millions of products and services in the market, there are less than 1,100 6-digit NAICS categories encompassing them all. Thus, by adopting NAICS for size standards, SBA has implicitly determined that small business size standards should be defined according to production processes, not according to products or services. When firms operating in different industries compete to supply same products or services, SBA may use this factor in setting size standards that ensure a level playing field for small businesses to participate in the Federal market.

Industry Growth Trends

This factor would take into consideration the overall trends in a particular industry, such as changes over time in firm size, concentration, and size distributions of firms. Like the other secondary factors, growth trends would lack a definitive influence on an industry's size standard analysis. There is no unambiguous upward or downward influence it would have on setting size standards. Additionally, because of changes to industry definitions (e.g., SIC to NAICS and NAICS updates every 5 years) and resultant inconsistencies in industry data over time, inclusion of this factor in the size standard is limited. However, with the release of 2012 Economic Census data, there now exist 15 years of industry data covering four Economic Censuses under NAICS. This would allow SBA to evaluate changes in industry structure and their impacts on size standards.

Unique History in the Industry

Prior correspondences or public comments, changes in Federal procurement policies, Congressional directives, financial indicators or other relevant information is retained by SBA's

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[33] Thus, while paper clips and bird cages are not competing products, they are produced in the same industry (NAICS 332618 "Fabricated Wire Products Manufacturing") due to the similarity of production process, *i.e.* bending metal wire. In contrast, containers for liquid food, such as fruit juices, come in a variety of types such as glass, plastic, paperboard and cans. Each of the four types of containers is produced in a different industry, but competes with each other for the juice container market because they are sufficiently substitutable so as to constitute a market.

Office of Size Standards for each industry. SBA will also evaluate and consider such historical information when establishing, reviewing, or revising a size standard. SBA also thoroughly evaluates all public feedback on its proposed rule before issuing the final rule.

Impacts on SBA and Other Programs

SBA also evaluates the impact of a size standard revision on its programs, including the volume of SBA guaranteed loans within an industry and the number and size of firms obtaining those loans. This is to assess whether the existing or revised size standard for a particular industry may be restricting access of financial assistance to firms in that industry. If the analysis shows that the proposed size standard based on the five primary factors (*i.e.*, average firm size, average assets size, 4-firm concentration ratio, distribution of firms by size, and Federal contracting factor) results in a significant reduction in the small business assistance compared to the existing size standard, a size standard higher than a proposed level would be adopted. If small businesses are already receiving the adequate level of financial assistance through SBA's loan programs, or if small businesses receiving the SBA's financial assistance are much smaller than the proposed or existing size standard, consideration of this factor may not be warranted when determining the size standard.

ASSESSING DOMINANCE IN FIELD OF OPERATION

Section 3(a) of the Small Business Act defines a small business concern as one that is (1) independently owned and operated, (2) not dominant in its field of operation, and (3) within a specific small business definition or size standard established by the SBA Administrator. SBA considers as part of its evaluation of a size standard whether a business concern at a proposed size standard would be considered dominant in its field of operation. Consistent with legislative history, this assessment generally considers the industry's market share of firms at the proposed size standard, or other factors that may show whether an individual firm can exercise a major controlling influence on significant numbers of business concerns at a national level. If SBA analysis indicates a proposed size standard would include a dominant firm, a lower size standard would be considered to exclude the dominant firm.

OTHER MEASURES OF SIZE STANDARDS

In limited situations, SBA selects a size standard measure that is unique to an industry. This generally occurs when the receipts or employee based measure does not adequately reflect the level of activity of firms within an industry. The selected size measure is a widely used measure of industry activity by industry analysts or by Federal statistical agencies. In addition, the availability of reliable industry data on the alternative size measure is also important. Below is a brief description of each of the three specific alternative measures of size standards that SBA is using today.

Barrels Per Calendar Day Refining Capacity

Since 1955, for purposes of Government procurement, SBA has always used 1,500 employees in conjunction with barrels per calendar day of refining capacity as the size standard for the petroleum refining industry. Currently, refining capacity is 200,000 barrels per

calendar day. Refining capacity is considered to be a better indicator for measuring and comparing the operations of petroleum refiners than both the number of employees and receipts. In 1992, SBA proposed eliminating the refining capacity component of the size standard for refiners and using the 1,500-employee size standard only. However, industry comments overwhelmingly favored retaining refining capacity as part of size standard for the petroleum refining industry. Moreover, several other Federal agencies, such as the U.S. Department of Energy and Environmental Protection Agency, also use the refining capacity as a measure to differentiate one refiner from another. The employee component in refining size standard is necessary to account for affiliation involving entities not engaged in refining activity.

For establishing a size standard based on refining capacity, SBA generally follows its standard approach to analyzing industry structure. For example, average firm size, distribution of firms by size, and concentration ratios, and Federal contracting participation are analyzed in terms of refining capacity. Depending on the availability relevant data, starts up costs are also evaluated. In lieu of the percentile distribution as for the receipts and employee based standards, SBA focuses its analysis on changes in the industry structure since the previous adjustment to the size standard and the historic size of small business segment in the industry.

Total Assets

In 1984, SBA established a size standard of $100 million in total assets for industries in the banking sector. To establish that size standard, SBA analysis focused in the average assets size of banks and the distribution of banks by assets size. It also considered the number of bank branches at a particular size, as well as whether the bank had the capability for electronic fund transfers. The Agency also took into consideration the opinions of industry experts on what constitutes a small bank. The consensus view supported the SBA estimate of $100 million standard in total assets. As part of the recently completed comprehensive size standards review, in 2013, SBA increased the assets based size standard to $500 million (78 FR 37409 (June 20, 2013)). This was further increased to $550 million in 2014 as the result of adjustment of all monetary based size standards for inflation (79 FR 33647 (June 12, 2014)).

Tangible Net Worth and Net Income

SBA does not apply tangible net worth and net worth as measures of business size for industry based size standards. However, participants to the SBA's Small Business Investment Company (SBIC), 7(a), and Certified Development Company (CDC/504) programs can qualify as small business concerns under an alternate size standard that is based on tangible net worth and average net income, in addition to industry bases size standards. SBA's decisions on the levels of size standards in terms of tangible net worth and net income generally reflect the objectives of the program and characteristics of its intended beneficiaries. For example, to establish the tangible and net income based size standard, SBA generally examines the maximum level of investment to businesses by a SBIC licensee and the overall level of financing by all investors. The current alternative standard for the SBIC program is at $19.5 million in net worth and $6.5 million in net income.

With the enactment of the Jobs Act in 2010, Congress established a new temporary alternative size standard of tangible net worth of not more than $15 million and net income of not more than $5 million for SBA's 7(a) and 504 loan programs ("Interim Rule"), thereby

replacing the existing alternative size standard of $8.5 million in tangible net worth and $3 million in net income, then set forth in 13 CFR 121.301(b)(2). The Jobs Act also provided the Interim Rule would remain in effect for the 7(a) and CDC/504 loan programs until SBA has established a permanent tangible net worth and net income based size standard through rulemaking. SBA has not yet established such size standard and continues to apply the Interim Rule to define a small business concern for those programs, in addition to using the industry based size standards.

ADJUSTMENT TO MONETARY BASED SIZE STANDARDS FOR INFLATION

SBA makes adjustments to its monetary based size standards when necessary. In accordance with its regulations (13 CFR 121.102), SBA assesses the impact of inflation on monetary based size standards at least once every five years. This assures the public that SBA monitors inflation and decides whether to adjust size standards at least that often, if not more frequently. Inflation adjustments are separate changes in addition to those made through an analysis of industry structure and Federal market conditions; they are intended to maintain the real value of a monetary based size standard until a more detailed size standards analysis may be conducted. SBA made adjustments to monetary size standards for inflation in 2014, 2008, 2005, 2002, 1994, 1984 and 1975.

To calculate an inflation adjustment, SBA follows the following steps:

1. Determine an inflation index to represent the change in monetary value from one period to the next. There are a number of inflation indexes that the Federal government produces, but for all previous adjustments for inflation, SBA has opted to apply the chain-type price index for the Gross Domestic Product (GDP). The Bureau of Economic Analysis (BEA) publishes this index on a quarterly basis.

   For the 2014 inflation adjustment, SBA evaluated the various measures of inflation indexes for their appropriateness to use for adjusting its monetary based size standards for inflation. These include: the consumer price index, the producer price index, and the employment cost index from the Bureau of Labor Statistics (BLS); and the GDP chain-type price index and personal consumption expenditures price index from BEA. SBA also examined the value added and gross output price indexes by industry from BEA. Of all these inflation indexes reviewed, SBA determined that, being the most comprehensive measure of price movements for the overall economy, the GDP price index is the most appropriate measure for adjusting its size standards for inflation. The SBA's interim rule on the 2014 inflation adjustment provides a detailed discussion on each of the various measures of inflation (79 FR 33647 (June 12, 2014)).

2. Determine the base or starting period, which is usually the latest quarter for which GDP price index statistics were available at the time of previous inflation adjustment.

3. Determine the ending period, which is usually the latest quarter for which GDP price data are available at the time of current inflation adjustment.

4. Calculate the rate of inflation between base period and ending period as follows:

$$Rate\ of\ inflation\,(\%)$$
$$= \left(\frac{GDP\,PRICE\,INDEX_{End\ period} - GDP\,PRICE\,INDEX_{Base\ period}}{GDP\,PRICE\,INDEX_{Base\ period}} \right) \times 100$$

$$= \left(\frac{GDP\,PRICE\,INDEX_{End\ period}}{GDP\,PRICE\,INDEX_{Base\ periiod}} - 1 \right) \times 100$$

For the 2014 inflation adjustment, the first quarter of 2008 was used as the base period and the fourth quarter of 2013 was used as the ending period. When the rule was prepared, the chain-type price index for GDP was 98.5 for the first quarter of 2008 (base period) and 107.1 for the fourth quarter of 2013 (end period). Based on these values, using the above formula, rate of inflation was estimated to be 8.73% between the two periods.

$$Rate\ of\ inflation = \left(\frac{GDP\,PPRICE\,INDEX_{End\ period}}{GDP\,PRICE\,INDEX_{Base\ periiod}} - 1 \right) \times 100 = \left(\frac{107.1}{98.5} - 1 \right) \times 100 = 8.73\%$$

5. Adjust the monetary based size standards using the estimated rate of inflation and round the results off based on what SBA has chosen as the predetermined level. Generally, and most recently, SBA rounded off the result to the nearest $500,000.

$$Adjusted\ size\ standard_{End\ period}$$

$$= Size\ standard_{Base\ period} + Size\ standard_{Base\ period} \times Rate\ of\ inflation$$

The second term in the above formula is an increase in industry's size standard due to inflation. Adding this increase to the size standard at the base period (*i.e.*, current size standard at the time of adjustment) gives a new size standard adjusted for inflation, which is, in most cases, higher than the current standard.

If an industry's current size standard is $14 million in annual receipts, based on the 8.73% inflation rate, its size standard will be $15 million after being adjusted for inflation. Using the above formula,

$$Adjusted\ size\ standard_{End\ period}$$
$$= Size\ standard_{Base\ period} + Size\ standard_{Base\ period} \times Rate\ of\ inflation$$
$$= 14{,}000{,}000 + 14{,}000{,}000 \times 8.73\%$$
$$= 14{,}000{,}000\,(1 + 0.0873)$$
$$= 14{,}000{,}000 \times 1.0873$$
$$= \$15{,}222{,}200$$

Rounded to the nearest $500,000, this becomes $15 million.

ADOPTION OF NAICS REVISIONS FOR SIZE STANDARDS

In 2000, SBA adopted NAICS 1997 industry definitions as a basis for its table of small business size standards, replacing the Standard Industrial Classification (SIC) (65 FR 30836 (May 15, 2000)). Since then, the Office of Management and Budget (OMB) has issued four revisions to NAICS – NAICS 2002, NAICS 2007, NAICS 2012, and the latest NAICS 2017 revisions. To ensure that size standards are based on latest industry definitions, SBA updates its table of size standards following the release of a new NAICS revision from OMB. Currently, SBA is in the process of updating its size standards to adopt NAICS 2017 revisions (81 FR 52584 August 8, 2016)).

When SBA proposed to replace SIC with NAICS 1997 as the basis of industry definitions for its table of small business size standards, it established a set of guidelines or rules to convert the size standards from industries under SIC to those under NAICS (64 FR 57188 (October 22, 1999)). The guidelines aimed to minimize the impact of applying a new industry classification system on SBA's size standards and on small businesses that qualified as small under the SIC based size standards. SBA received no negative comments against the proposed guidelines. SBA published the final rule on May 15, 2000 (65 FR 30386) (corrected on September 5, 2000, 65 FR 53533) adopting the resulting table of size standards based on NAICS 1997, as proposed. To be consistent, SBA also applied the same guidelines when it updated its table of size standards to adopt NAICS 2002 (67 FR 52597 (August 13, 2002)), NAICS 2007 (72 FR 49639 (August 29, 2007)), and NAICS 2012 revisions (77 FR 49991 (August 20, 2012)). In all those updates too, SBA received no adverse comments on using those guidelines, or on the resulting changes to the size standards. For the current proposed rule to adopt NAICS 2017, SBA has also generally followed same guidelines. Those guidelines are shown below in Table 14.

Table 14

General Guidelines to Convert Size Standards from Old NAICS to New NAICS Industries

	If a new NAICS industry is composed of:	The size standard for the new industry will be:
1	A single old NAICS industry or part of a single old NAICS industry	The same size standard as for the old NAICS industry or part.
2	Two or more old NAICS industries; two or more parts of an old industry; parts of two or more old NAICS industries; or one or more old NAICS industries and part(s) of one or more old NAICS industries.	
	2a. they all have the same size standard	The same size standard as for the old NAICS industries or parts.

	2b. they all have the same size measure (*e.g.*, receipts, employees, etc.) but do not all have the same size standard	The same size standard as for the old NAICS industry or part that most closely matches the economic activity described by the new NAICS industry, or The highest size standard among the old NAICS industries and part(s) that comprise the new NAICS industry, provided that the highest size standard does not include dominant or potentially dominant firms.
	2c. they have different size measures (i.e., for example, some are based on receipts and others on employees) and hence do not all have the same size standard	The same size standard as for the old NAICS industry or part that most closely matches the economic activity described by the new NAICS industry, or The highest size standard among the old NAICS industries and part(s) that comprise the new NAICS industry, provided that the highest size standard does not include dominant or potentially dominant firms. To apply this rule, SBA converts all size standards to a single measure (e.g., receipts, employees, etc.) using the size measure for the old NAICS industry or part(s) that most closely match the economic activity described by the new NAICS industry or using the size measure that applies to most of the old NAICS industries or parts comprising the new NAICS industry.

In addition to the above general guidelines, in cases where a new industry is formed by merging multiple industries or their parts with substantially different levels or different measures of size standards, SBA also examines the relevant latest industry and Federal procurement data to determine an appropriate size standard for the new industry.

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Dated:

Linda E. McMahon,
Administrator.

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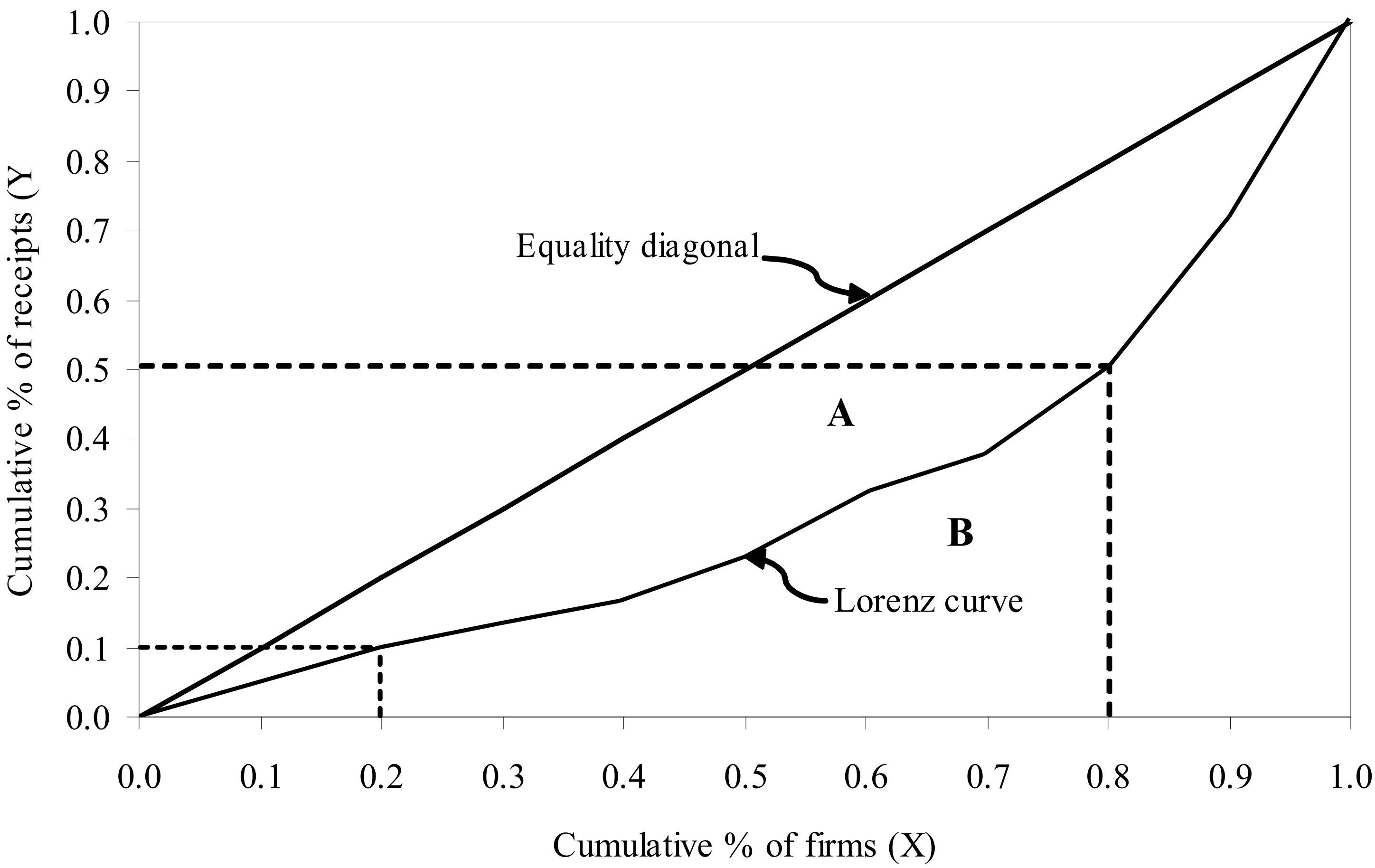

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